MOJAVE BLOOM

Team Las Vegas
Engineering Narrative

Contents

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U.S. DEPARTMENT OF ENERGY SOLAR DECATHLON UNLV

HVAC System

The home has a fully integrated heating, ventilation, and air conditioning (HVAC) system designed for simplicity, cost, redundancy, and ease of maintenance. Energy-efficient ceiling fans aid in the use of natural ventilation, the home's primary ventilation, when ambient conditions permit. When natural ventilation cannot maintain the comfort zone, the mechanical system provides ventilation. Energy-efficient exhaust fans remove latent and sensible loads such as kitchen, bath and laundry heat and humidity at the source. As the solar thermal system acts as the primary heating source, very energy-efficient mini-split heat pumps provide backup heating, cooling, and dehumidification. The home automation system integrates all these systems through monitoring ambient and home conditions to automatically select modes of operation.

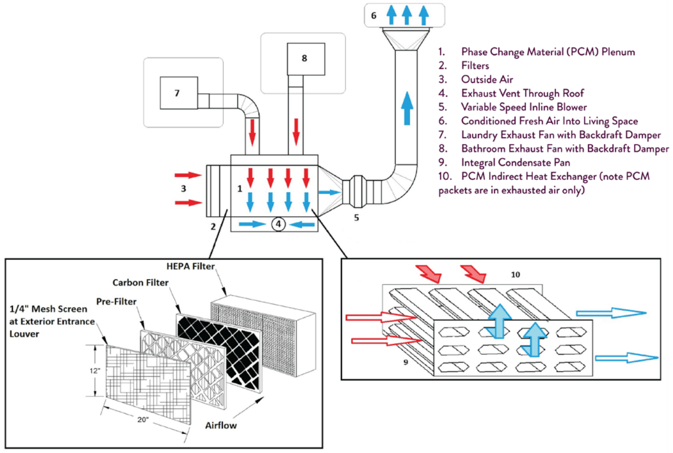


Diagram of HVAC System

The fresh air system uses Phase Change Materials (PCM) to condition fresh air before entering the home. It integrates filters to remove odors, allergens, and small particles from the fresh air to improve indoor air quality. This innovative system is compacted into a unit to house the PCM heat exchanger and peripheral components such as filters, blower, humidifier, and controls in the mechanical closet, and then is ducted into the condition space. The home automation system controls the fresh air conditioning system as well as monitors CO2, home fresh air requirements, and ambient conditions to optimize operation and indoor air quality.

The PCM lessens the effects of outdoor air temperatures, thus decreasing the air conditioning required to heat or cool the fresh air. The PCM used is a commercially available encapsulated eutectic salt contained in foil packets. Approved for installation in the active plenum, the salts are flame resistant and do not put out harmful gases or fumes when heated. The PCM is designed to "freeze" and "thaw" at 78 degrees F which is ideal for ventilation applications. Installed in a heat exchanger in the fresh air inlet, the PCM melts at high ambient temperatures and absorbs heat from incoming air. During colder ambient conditions such as cooler evening hours, the absorbed heat rejects into the ambient or heats the incoming air, allowing the PCM to re-freeze. Testing at UNLV has

HVAC System

shown that the PCM installed in the active fresh air plenum greatly reduces the energy required to heat or cool incoming fresh air.

The home has two mini-split heat pumps located in the main living room area and the bedroom. Using two units allows redundancy in the systems in case of service issues. Also, two systems increase efficiency during partial load conditions, when only one unit is required to cool the interior space. The unit in the living room area is located to direct air towards the kitchen area, doors, windows, and hall to better condition the associated loads. The unit in the bedroom is positioned to not only cool the bedroom but also direct air towards the hall and living area. Exhaust in the bathroom and laundry area draw conditioned air into these spaces.

For cooling, the mini-split heat pumps operate using direct expansion (DX) refrigeration. The indoor coils perform at temperatures below the dew point allowing the heat pumps to dehumidify. If the room temperatures are already in the comfort zone, but the humidity is too high, the units run at low-speed cooling or dehumidification mode. The radiant heating then reheats the space to maintain the comfort zone. Condensate from dehumidification drains to the exterior of the house and waters the landscape. The units are equipped with large particle air filters, anti-allergy enzyme filters, and deodorizing filters to help maintain air quality. These filters are designed to be easily removed, hand washed, and reused for serviceability.

The outdoor units of the heat pumps are located in the mechanical equipment room installed on a rack, with the fans rejecting heat directly out a large free-area louver. The mechanical equipment room has louvers on opposite walls to allow cross ventilation in the room. The outdoor units remove air which helps reject heat from other components, such as the battery system. The heat pumps can use the heat from the other components if needed to operate in the heating mode. A drain pan installed beneath the units collects condensate from the heating defrost cycle. This condensate is also used to water the landscape. The units are installed with the required service and electrical clearances.

The home automation system controls the mini-split heat pumps; however, in the event of a failure of the system, the heat pumps are capable of operating in a stand-alone mode using its own controls. The home automation advises the home occupants on the operational status of the systems, temperatures, humidity, any required services like filter cleaning, and any detected service issues. The automation also commands the operating periods of the units. This allows load sharing and shedding to reduce peak loads, such as when the home is running on the battery system or during Demand Response events.

Solar Thermal System

The home uses a solar thermal system for domestic hot water and radiant heating. The system has an evacuated tube collector located on the southwest corner of the home connected to a solar storage tank found in the equipment room on the west side of the home. The controls of the system are integrated into the home automation system, so that the solar thermal system is the primary source for hot water and heating.

The system is designed with three isolated water filled systems. The first loop connects a heat exchanger located at the bottom of the storage tank to the solar collector. The second loop connects a heat exchanger found at the top of the storage tank to the radiant system. The volume of the tank is used for domestic hot water.

The system has an evacuated tube collector that mounts vertically in a small recess on the south wall for transportation of the home. A unique concept of the installation is that when the home is set up, the collector can be set to the ideal installation angle. This adjustment is made when two metal brackets located on the header of the collector are loosened to allow the bottom of the collector and support structure to rotate away from the home. After the brackets and two base supports are tightened, the solar loop is filled. This installation allows the collector to be pitched to the ideal installation angle suitable for different locations, seasonally, or to optimize the heat collected for the needed water use. The bottom of the collector, angled away from the house, is protected with a planter located under the collector.

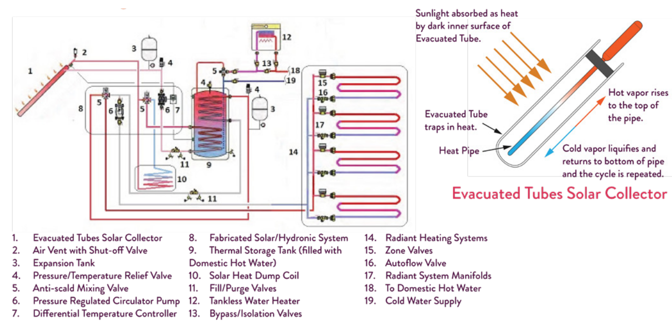
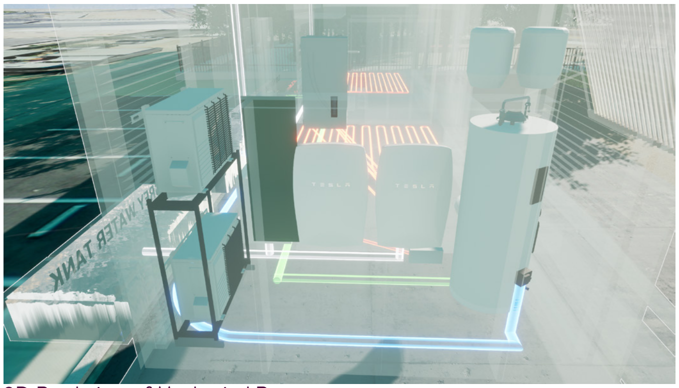


Diagram of Solar Thermal/Hot Water System Systematic



3D Renderings of Mechanical Room

Another unique aspect of the installation is the design of a compact unit that houses the peripheral components of the solar thermal system. It is a condensed, insulated box that contains the pumps, mixing and fill valves, and controls of the solar thermal system. This box is designed to minimize the space normally needed for this type of system yet still have the components easily serviceable. It can be mounted on the wall

Solar Thermal System

or on the solar thermal storage tank to reduce the number of interconnecting pipes of the system, as well as only requiring piping connections to be made. Since the box is insulated, larger components such as pumps, mixing valves and associated piping do not need to be insulated. Temperatures monitored for the operation of the system and the system status are displayed on the access cover of the box. This box is made as an innovative product that could simplify the installation of the complete solar thermal systems on any project.

The insulated pipes for the isolated solar collector loop are kept to a minimum length to decrease heat loss, increase system efficiency, and lower any possible damage from system water leaks. The system is equipped with the required fill and check valves, air purge, Temperature and Pressure Relief (T&P) valve, and an expansion tank. The expansion tank and T&P valve are plumbed, so they cannot be isolated from the collector heat source. A mixing valve maintains the tank temperature and prevents "stagnation" of the system. This mixing valve feeds from the collector into the hot input, as well as feeds from a pipe heat dump on the cold side. The mixed output is set to the maximum storage tank temperature. As the tank comes to temperature, the hot side of the valve closes and forces the hot water through a tee fitting to the heat dump. After the heat is rejected into the ambient, the cooled water returns to the cold side of the valve. A long length of exposed pipe is used for the heat dump.

The isolated radiant loop of the system is heated through the heat exchanger located at the top of the solar storage tank. This loop has a circulation pump that runs only when radiant heating is required. The loop also has an expansion tank and T&P valve that cannot be isolated from the tank heat exchanger heat source. Another mixing valve controls the radiant system maximum temperature. The hot water from the tank heat exchanger feeds into the hot input of the valve. A tee fitting in the return line of the radiant manifold feeds the cold side. The mixed output from the valve feeds into the radiant distribution manifold which controls the flow to the different radiant zones. As zones from the radiant system are energized, the pump is energized, and water flows through the tank heat exchanger to be heated. As long as the tank temperature is above needed water temperature of 90 degree F, the hot side of the mixing valve closes down and draws water from the cold side. The cold water drawn from the return side of the manifold is then at the cooler room temperature. The pump is also located on the return side and feeds water to the heat exchanger or the cold side of the valve.

Solar Thermal System

The radiant system uses PEX tubing for radiant floor heating distribution throughout the home, as well as radiant appliances, such as radiant towel heaters for the bathroom. The radiant floor system has PEX tubing installed in grooves in the subfloor with aluminum heat distribution plates. Likewise, the pipe lengths are kept to a minimum when possible to lower the fill volume. Since it is an isolated system, there is minimal water damage, if there are any water leaks in the system. Water only leaks out if the system loses its fill pressure. Any leak in a zone is isolated at the distribution manifold until repairs are made.

Domestic cold water feeds the solar thermal storage. The water drawn from the tank is used for domestic hot water and goes through a mixing valve to maintain hot water temperature. The tank volume feeds the hot side of the valve and the domestic cold water feeds the cold side. The mixed side of the valve is set to the desired hot water temperature. The storage tank is equipped with a T&P valve that is suitable for the tank and water temperature. If there is not enough hot water in the storage tank, an on-demand electric water heater is installed after the mixing valve, to heat only the domestic hot water. The temperature control for the heater is set at a lower temperature than the mixing valve temperature. The system is equipped with isolation valves for both the storage tank and the water heater, so that either can be isolated for repairs.

A domestic hot water recirculation pump maintains hot water at the kitchen sink, the furthest fixture from the storage tank. Temperature, time of use, or manual operation on a smart device controls the pump. The main hot water circulation loop piping is sized to allow hot water at the fixtures to use less than 2 cups of water.

AC Electrical System

The home runs on alternating current (AC) electricity at 120/240 volts and 60 Hertz. The home is fed through a utility meter panel with a main circuit breaker located on the exterior of the home. The location of the meter panel and main circuit breaker are at the west end of the building on the north side of the mechanical room door. They are located on the exterior of the mechanical room to minimize lengths and simplify large electrical loads. The main breaker feeds through a Tesla Energy Gateway grid isolation switch that isolates the interior mounted sub panel when the grid is down and the home is operating on battery power. The subpanel is the distribution panel for all electrical loads of the home and has integrated energy monitoring. The subpanel mounted in the mechanical room again minimizes large load wire lengths, such as the electric on-demand water heater, heat pumps, photovoltaic inverters, battery storage systems, and the home booster pump. For the meters and panels, Schneider Electric Square

AC Electrical System

D panels are used. The subpanel that feeds all the branch circuit loads is equipped with Schneider Electric residential energy monitoring. With the large load systems located adjacent to the subpanel, it negates the need for service disconnects mounted at each system found in the mechanical room and further reduces system cost.

The home has a battery storage system using two Tesla Powerwall 2.0 with AC output. The system is designed and sized to meet the requirements of the competition and provide backup power to the home. It also acts as storage of energy produced during the day from the photovoltaic (PV) system for disbursement at night or during peak power periods. The AC output batteries are back fed directly into the subpanel. The system can operate in an off-grid mode with the PV system recharging the batteries during the day. The batteries have integral cooling systems that reject heat through the cross ventilation of the mechanical room or by the fans of the heat pumps.

The main house and grid loads, as well as the state of charge of the batteries, are monitored to operate the batteries efficiently. During periods of high electrical loads, such as electric car charging or air conditioning, the home automation system uses schemes like load shedding and sharing to reduce battery current draws. The system turns one air conditioner off while the other continues to run, and then alternates operation to maintain temperatures. Temperatures are setback from the comfort zone for short periods to help reduce electrical loads. Other devices disconnect or advise the occupants of the need to reduce electrical loads during these periods.

The home also has a roof mounted photovoltaic system that handles the required energy needs of the home for net zero energy operation. The panels on the roof have the required access clearances around the systems. Photovoltaic panels and racking are lowered to horizontal position for transport and then adjusted to 10 degrees for National Showcase. Refer to sheet E-108 Photovoltaic Racking Details.

The PV system uses a single inverter located in the mechanical room that feeds into a utility required renewable energy meter and disconnect found on the exterior of the home, adjacent to the utility power meter. The two AC batteries feed into the subpanel, so that the PV system operates in the islanding mode when the subpanel is isolated from the grid. For the PV system, each panel uses DC optimizers to optimize panel performance. The system has roof mounted DC disconnects and DC wiring run in conduit from the roof to the inverter.

Home Automation System

The home's automation is based on the Insteon Home Automation System however uses several integrated components to control the various home systems. The Insteon system has dual band communications which include both Power Line Carrier (PLC) and Radio Frequency (RF). Using dual bands allows the system to communicate through devices powered on different phases of the split phase home electrical system without using communications phase couplers. This also allows communications through devices powered by transformers that do not pass PLC signals. The Insteon devices used include controlled receptacles, dimmer switches, on/off switches, thermostats, and an irrigation controller.

For temperature measurements, the automation system has three Smartenit EZI08 Input/Output Controllers. Each controller uses a DS18B20 1-wire digital temperature sensor to measure the solar thermal collector, the solar thermal storage tank, and the hot water recirculation pump return line. One of the controller's output relays is used with a 24 volt AC transformer to control the five radiant floor manifold actuators. Each controller connects to an Insteon Powerlinc Modem (PLM) to allow communications to the Insteon system. These PLMs are each plugged into the home's electrical outlets.

The system uses a Universal Devices ISY994i ZW IR PRO for the automation controller which allows programmed logic routines. The device is connected to the Insteon system through a PLM plugged into a receptacle and also connected to the local area network (LAN) router. It is programmed through a Graphical User Interface (GUI). Using the temperature signals from the I/O controllers, the automation controller controls the receptacles that the solar thermal pump, radiant floor pump, and hot water recirculation pump are plugged into. It also sends out the signals to actuate the radiant floor manifold valve actuators.

The home uses two Global Cache iTach WFrIR WiFi to Infrared (IR) transceivers. These devices allow the reproduction of the IR control signals of devices used in the home. These include the two mini-split heat pumps, two ceiling fans, and home entertainment devices such as the television and Blu Ray DVD player. These devices are connected through WiFi to the automation controller. This allows the control of these systems through programmed schemes, smart devices, or an Amazon Echo.

For sensing room temperatures and humidity, the system uses two Insteon thermostats located in the two major zones of the home. These thermostats connect wirelessly to the

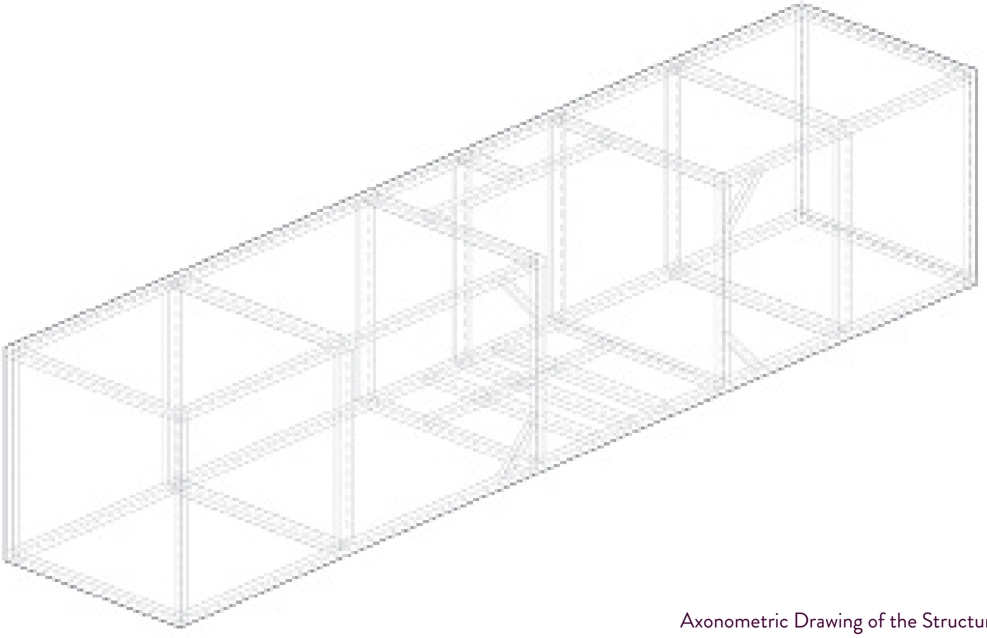
Home Automation System

Insteon system but are powered through a hardwired transformer. The thermostats are used to cycle between the radiant floor.

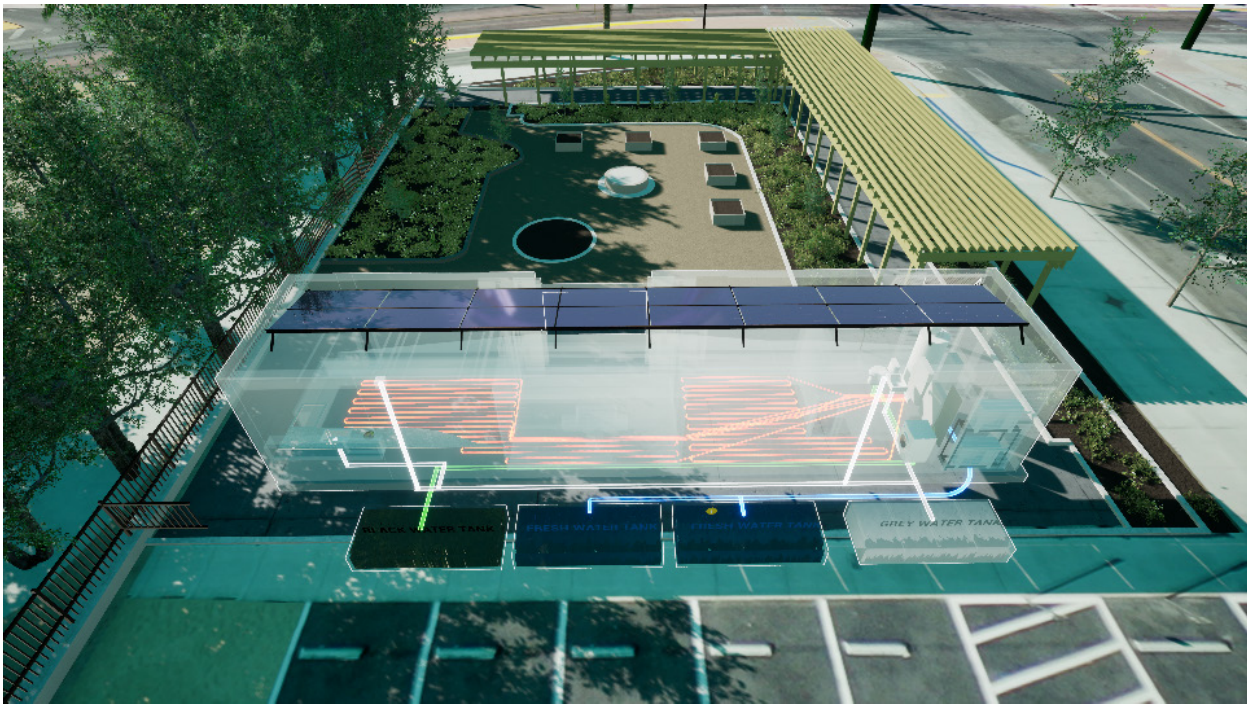
Structural Engineering

For the structural design, the home will be framed with Ahern's Extreme Cube Space Framing. It offers a solid structural design, and simplifies transportation of the home with forklifting capability. Within the Extreme Cube Spaceframe, there will be well-insulated walls, roofs, and floors that utilize framing techniques, as well as energy efficient windows and doors. The home will maintain thermal comfort through passive architectural design strategies and active engineering systems.

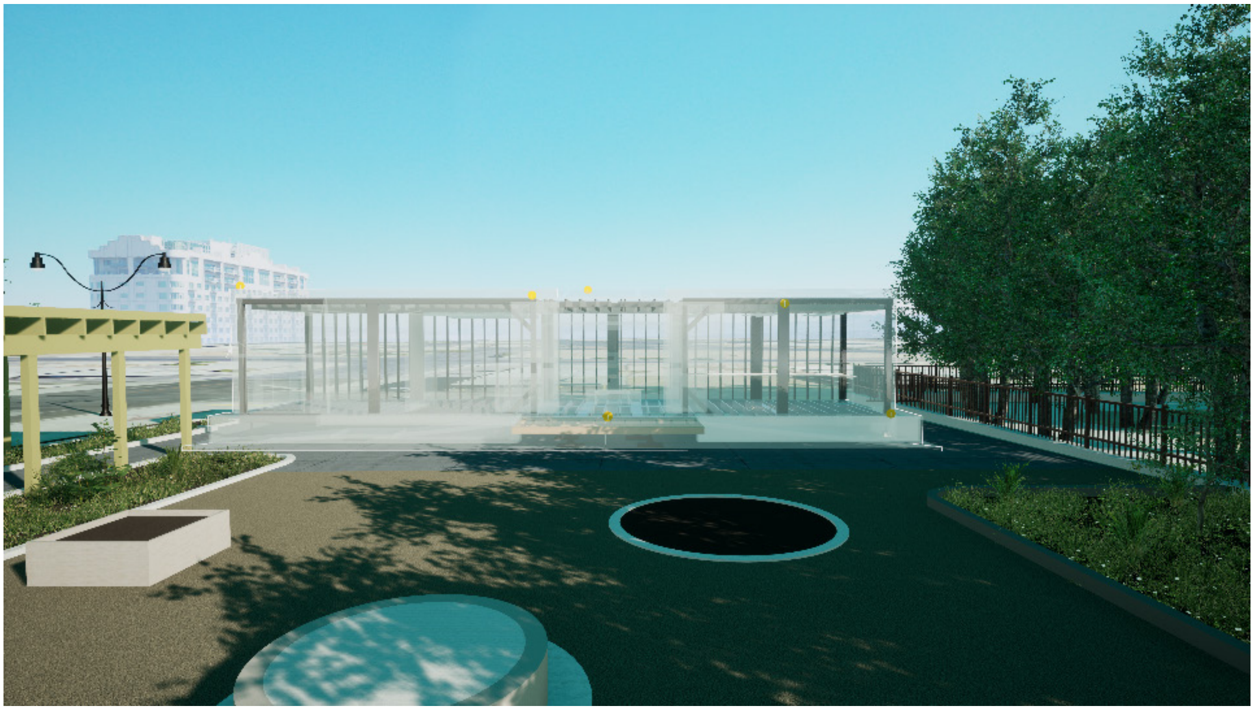
Structural Steel Framing



Axonometric Drawing of the Structural System



3D Rendering of Radiant System



3D Rendering of the Structural Diagram

U.S. DEPARTMENT OF ENERGY SOLAR DECATHLON

Energy Analysis and Engineering Narrative

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The fresh air system uses Phase Change Materials (PCM) to condition fresh air before entering the home. It integrates filters to remove odors, allergens, and small particles from the fresh air to improve indoor air quality. This innovative system is compacted into a unit to house the PCM heat exchanger and peripheral components such as filters and controls in the mechanical room, and then is ducted into the condition space. The filters are a pleated pre-filter, an activated carbon filter, and a 99.97% HEPA filter. The home automation system controls the fresh air conditioning system as well as monitors CO2, home fresh air requirements, and ambient conditions to optimize operation and indoor air quality.

The PCM lessens the effects of outdoor air temperatures, thus decreasing the air conditioning required to heat or cool the fresh air. The PCM used is a commercially available encapsulated eutectic salt contained in foil packets. Approved for installation in the active plenum, the salts are flame resistant and do not put out harmful gases or fumes when heated. The PCM is designed to “freeze” and “thaw” at 78 degrees F which is ideal for ventilation applications. Installed in a heat exchanger in the fresh air inlet, the PCM melts at high ambient temperatures and absorbs heat from incoming air. During colder ambient conditions such as cooler evening hours, the absorbed heat rejects into the ambient or heats the incoming air, allowing the PCM to re-freeze. Bathroom and laundry exhaust are blown over the PCM packet in the exhaust air stream to allow energy recovery before exhausting outdoors. Testing at UNLV has shown that the PCM installed in the active fresh air plenum greatly reduces the energy required to heat or cool incoming fresh air.

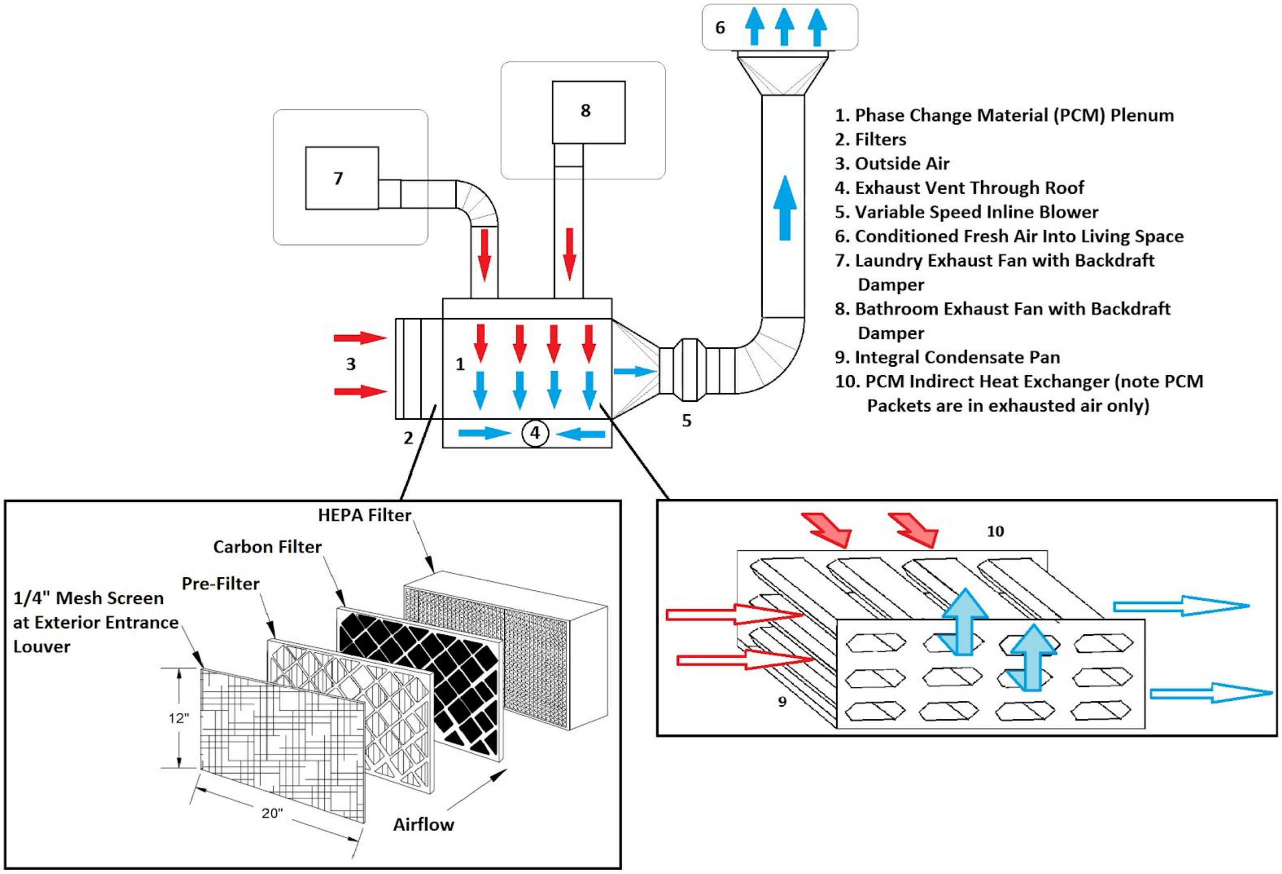
The home has two mini-split heat pumps located in the main living room area and the bedroom. Using two units allows redundancy in the systems in case of service issues. Also, two systems increase efficiency during partial load conditions, when only one unit is required to cool the interior space. The unit in the living room area is located to direct air towards the kitchen area, doors, windows, and hall to better condition the associated loads. The unit in the bedroom is positioned to not only cool the bedroom but also direct air towards the hall and living area. Exhaust in the bathroom and laundry area draw conditioned air into these spaces.

For cooling, the mini-split heat pumps operate using direct expansion (DX) refrigeration. The indoor coils perform at temperatures below the dew point allowing the heat pumps to dehumidify. If the room temperatures are already in the comfort zone, but the humidity is too high, the units run at low-speed cooling or dehumidification mode. The radiant heating then reheats the space to maintain the comfort zone. Condensate from dehumidification drains to the exterior of the house and waters the landscape. The units are equipped with large particle air filters, anti-allergy enzyme filters, and deodorizing filters to help maintain air quality. These filters are designed to be easily removed, hand washed, and reused for serviceability.

The outdoor units of the heat pumps are located in the mechanical equipment room installed on a rack, with the fans rejecting heat directly out a large free-area louver. The mechanical equipment room has louvers on opposite walls to allow cross ventilation in the room. The outdoor units remove air which helps reject heat from other components, such as the battery system. The heat pumps can use the heat from the other components if needed to operate in the heating mode. A drain pan installed beneath the units collects condensate from the heating defrost cycle. This condensate is also used to water the landscape. The units are installed with the required service and electrical clearances.

The home automation system controls the mini-split heat pumps; however, in the event of a failure of the system, the heat pumps are capable of operating in a stand-alone mode using their own controls. The home automation advises the home occupants on the operational status of the systems, temperatures, humidity, any required services like filter cleaning, and any detected service issues. The automation also commands the operating periods of the units. This allows load sharing and shedding to reduce peak loads, such as when the home is running on the battery system or during Demand Response events.

PCM System



Solar Thermal System

The home uses a solar thermal system for domestic hot water and radiant heating. The system has an evacuated tube collector located on the southwest corner of the home connected to a solar storage tank found in the equipment room on the west side of the home. The controls of the system are integrated into the home automation system, so that the solar thermal system is the primary source for hot water and heating.

The system is designed with three isolated water filled systems. The first loop connects a heat exchanger located at the bottom of the storage tank to the solar collector. The second loop connects a heat exchanger found at the top of the storage tank to the radiant system. The volume of the tank is used for domestic hot water.

The system has an evacuated tube collector that mounts vertically in a small recess on the south wall for transportation of the home. A unique concept of the installation is that when the home is set up, the collector can be set to the ideal installation angle. This adjustment is made when two metal brackets located on the header of the collector are loosened to allow the bottom of the collector and support structure to rotate away from the home. After the brackets and two base supports are tightened, the solar loop is filled. This installation allows the collector to be pitched to the ideal installation angle suitable for different locations, seasonally, or to optimize the heat collected for the needed water use. The bottom of the collector, angled away from the house, is protected with a planter located under the collector.

Another unique aspect of the installation is the design of a compact unit that houses the peripheral components of the solar thermal system. It is a condensed, insulated box that contains the pumps, mixing and fill valves, and controls of the solar thermal system. This box is designed to minimize the space normally needed for this type of system yet still have the components easily serviceable. It can be mounted on the wall or on the solar thermal storage tank to reduce the number of interconnecting pipes of the system, as well as only requiring piping connections to be made. Since the box is insulated, larger components such as pumps, mixing valves and associated piping do not need to be insulated. Temperatures monitored for the operation of the system and the system status are displayed in the box. This box is made as an innovative product that could simplify the installation of the complete solar thermal systems on any project.

The insulated pipes for the isolated solar collector loop are kept to a minimum length to decrease heat loss, increase system efficiency, and lower any possible damage from system water leaks. The system is equipped with the required fill and check valves, air purge, Temperature and Pressure Relief (T&P) valve, and an expansion tank. The expansion tank and T&P valve are plumbed, so they cannot be isolated from the collector heat source. A mixing valve maintains the tank temperature and prevents "stagnation" of the system. This mixing valve feeds from the collector into the hot input, as well as feeds from a pipe heat dump on the cold side. The mixed output is set to the maximum storage tank temperature of 165°F. As the tank comes to temperature, the hot side of the valve closes and forces the hot water through a tee fitting to the heat dump. After the heat is rejected into the ambient, the cooled water returns to the cold side of the valve. A long length of exposed pipe under the mechanical room is used for the heat dump.

The isolated radiant loop of the system is heated through the heat exchanger located at the top of the solar storage tank. This loop has a circulation pump that runs only when radiant heating is required. The loop also has an expansion tank and T&P valve that cannot be isolated from the tank heat exchanger heat source. Another mixing valve controls the radiant system maximum temperature of 90°F. The hot water from the tank heat exchanger feeds into the hot input of the valve. A tee fitting in the return line of the radiant manifold feeds the cold side. The mixed output from the valve feeds into the radiant distribution manifold which controls the flow to the five different radiant zones. As zones from the radiant system are energized, the pump is energized, and water flows through the tank heat exchanger to be heated. As long as the tank temperature is above 130°F, the hot side of the mixing valve closes down and draws water from the cold side. The cold water drawn from the return side of the manifold is then at the cooler room temperature. The pump is also located on the return side and feeds water to the heat exchanger or the cold side of the valve.

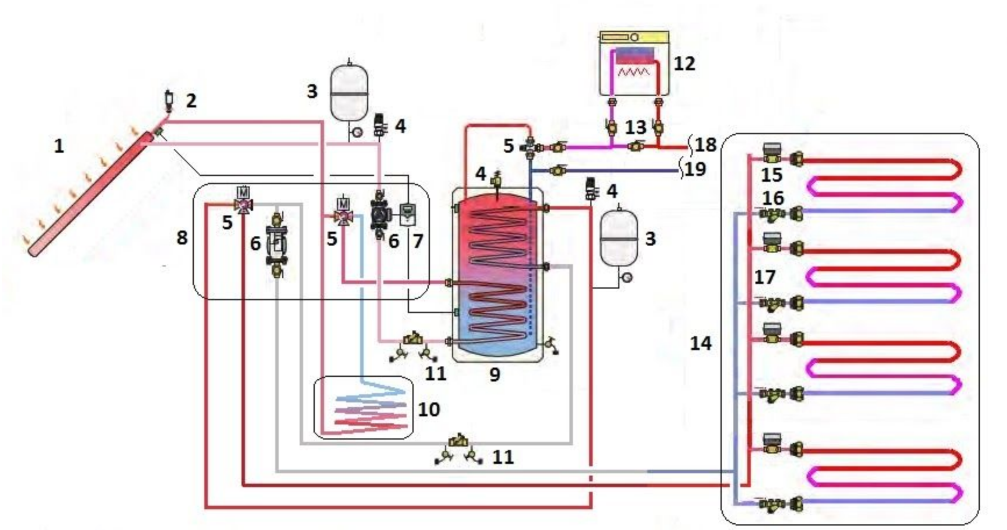
The radiant system uses PEX tubing for radiant floor heating distribution throughout the home, as well as radiant appliances, such as radiant towel heaters for the bathroom. The radiant floor system has PEX tubing installed in grooves in the subfloor with aluminum heat distribution plates. Likewise, the pipe lengths are kept to a minimum when possible to lower the fill volume. Since it is an isolated system, there is minimal water damage, if there are any water leaks in the system. Water only leaks out if the system loses its fill pressure. Any leak in a zone is isolated at the distribution manifold until repairs are made.

Domestic cold water feeds the solar thermal storage. The water drawn from the tank is used for domestic hot water and goes through a mixing valve to maintain hot water temperature. The tank volume feeds the hot side of the valve and the domestic cold water feeds the cold side. The mixed side of the valve is set to the desired hot water temperature. The storage tank is equipped with a T&P valve that is suitable for the tank and water temperature.

If there is not enough hot water in the storage tank, an on-demand electric water heater is installed after the mixing valve, to heat only the domestic hot water. The temperature control for the heater is set at a lower temperature than the mixing valve temperature. The system is equipped with isolation valves for both the storage tank and the water heater, so that either can be isolated for repairs.

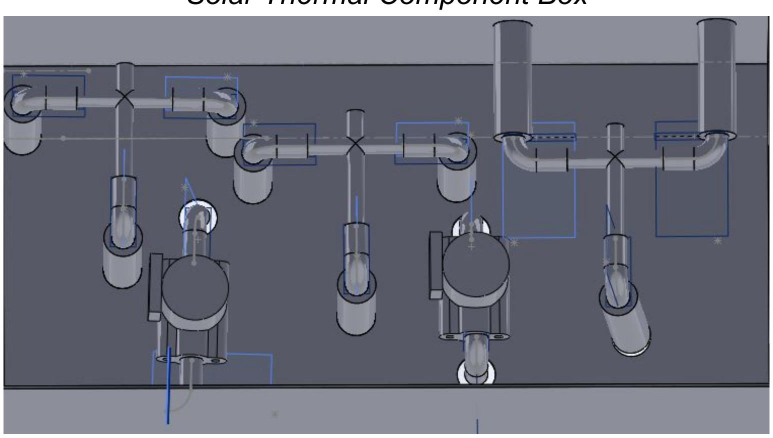
A domestic hot water recirculation pump maintains hot water at the kitchen sink, the furthest fixture from the storage tank. Temperature, time of use, or manual operation on a smart device controls the pump. The main hot water circulation loop piping is sized to allow hot water at the fixtures to use less than 2 cups of water.

Solar Thermal System Diagram



1. Evacuated Tubes Solar Collector
2. Air Vent with Shut-off Valve
3. Expansion Tank
4. Pressure/Temperature Relief Valve
5. Anti-scald Mixing Valve
6. Pressure Regulated Circulator Pump
7. Differential Temperature Controller
8. Fabricated Solar/Hydronic System
9. Thermal Storage Tank (filled with Domestic Hot Water)
10. Solar Heat Dump Coil
11. Fill/Purge Valves
12. Tankless Water Heater
13. Bypass/Isolation Valves
14. Radiant Heating System
15. Zone Valves
16. Autoflow Valve
17. Radiant System Manifolds
18. To Domestic Hot Water
19. Cold Water Supply

Solar Thermal Component Box



Another unique aspect of the installation is the design of a compact unit that houses the peripheral components of the solar thermal system. This unit consists of a compact insulated box containing the pumps, mixing and fill valves, radiant manifold, and controls of the solar thermal system. This box is designed to minimize the space normally needed for this type of system but still have all of the components easily serviceable. Temperatures monitored for the operation of the system and the system status are displayed on the access cover of the box.

AC Electrical System

The home runs on alternating current (AC) electricity at 120/240 volts and 60 Hertz. The home is fed through a utility meter panel with a main circuit breaker located on the exterior of the home. The location of the meter panel and main circuit breaker are at the west end of the building on the north side of the mechanical room door. They are located on the exterior of the mechanical room to minimize wire lengths and simplify large electrical loads. The main breaker feeds through a Tesla Energy Gateway grid isolation switch that isolates the interior mounted sub panel when the grid is down and the home is operating on battery power. The subpanel is the distribution panel for all electrical loads of the home and has integrated energy monitoring. The subpanel mounted in the mechanical room again minimizes large load wire lengths, such as the electric on-demand water heater, heat pumps, photovoltaic inverters, battery storage systems, and the home booster pump. For the meters and panels, Schneider Electric Square D panels are used. The subpanel that feeds all the branch circuit loads is equipped with Schneider Electric Energy Wiser residential energy monitoring. With the large load systems located adjacent to the subpanel, it negates the need for service disconnects mounted at each system found in the mechanical room and further reduces system cost.

The home has a battery storage system using two Tesla Powerwall 2.0 with AC output. The system is designed and sized to meet the requirements of the competition and provide backup power to the home. It also acts as storage of energy produced during the day from the photovoltaic (PV) system for disbursement at night or during peak power periods. The AC output batteries are back fed directly into a combiner panel and then the subpanel. The system can operate in an off-grid mode with the PV system recharging the batteries during the day. The batteries have integral cooling systems that reject heat through the cross ventilation of the mechanical room or by the fans of the heat pumps.

The main house and grid loads, as well as the state of charge of the batteries, are monitored to operate the batteries efficiently. During periods of high electrical loads, such as electric car charging or air conditioning, the home automation system uses schemes like load shedding and sharing to reduce battery current draws. The system turns one air conditioner off while the other continues to run, and then alternates operation to maintain temperatures. Temperatures are setback from the comfort zone for short periods to help reduce electrical loads. Other devices disconnect or advise the occupants of the need to reduce electrical loads during these periods.

The home also has a roof mounted photovoltaic system that handles the required energy needs of the home for net zero energy operation. The panels on the roof have the required access clearances around the systems. Photovoltaic panels and racking are lowered to horizontal position for transport and then adjusted to 10 degrees for National Showcase. Refer to sheet E-108 Photovoltaic Racking Details.

The PV system uses a single inverter located in the mechanical room that feeds into a utility required renewable energy meter and disconnect found on the exterior of the home, adjacent to the utility power meter. The two AC batteries feed into the subpanel, so that the PV system operates in the islanding mode when the subpanel is isolated from the grid. For the PV system, each panel uses DC optimizers to optimize panel performance. The system has roof mounted DC disconnects and DC wiring run in conduit from the roof to the inverter.

Home Automation System

Several processes in the home are automated both to make the house more livable and to keep the indoor air quality at optimal levels. To achieve this, the home has a local server on a Raspberry Pi Model 4 B that hosts Home Assistant, an open source automation software that is widely customizable and able to integrate data gathering systems with response systems.

The home automation starts with data gathering. Metrics of interest include CO2 levels within the home, relative humidity and temperature of the indoor air, the temperature of various parts of the solar hot water heating system. CO2 levels, relative humidity, and indoor temperature are all monitored by Netatmo sensors throughout the house. These sensors gather data continuously, once every 10 minutes, or, if desired, on demand. That data is used to trigger responses in various mechanical systems throughout the house to keep each indoor air quality metric within its optimal range. In addition to monitoring air quality, the system employs three Dallas Semiconductor High Precision 1-Wire Digital Thermometers wired to a single Wi-Fi-enabled Tasmota microcontroller that relays water temperature data from the solar collector, the solar hot water tank, and the domestic hot water return line contained in the solar hot water heating system to the automation system every 10 seconds. This data is used to cycle the solar pump when the collector is warmer than the tank or when the tank temperature setting is satisfied. The operation of the heat pumps in heating mode are enabled if the tank temperature is below 130 degrees F. The domestic hot water recirculation pump is cycled off when the return water reaches the set point.

Once data is collected, the system uses basic conditional logic to enable or disable various parts of the electrical and mechanical systems in the home to maintain the optimal conditions. To keep CO2 levels between 500 and 800ppm, the system controls an Insteon smart outlet that itself controls power to a fresh air fan that brings in fresh air that is filtered through a pleated pre-filter, a carbon filter, and a 99.97% HEPA filter. Once the home is comfortably within that prescribed range, the automation system cycles the fresh air fan off. The bathroom exhaust fan is also controlled by an Insteon switch that can be set to cycle with the fresh air fan to reduce CO2 and humidity. Integrated into the fresh air intake system is a selectively operable humidifier that is itself controlled by a separate Insteon smart outlet to keep relative humidity of the indoor air between 30%-50%. Indoor temperature is regulated by a couple of systems. Primary heating is accomplished by the radiant floor heating system with five zones in the home and is controlled by five solenoid valves connected to a Wi-Fi-enabled Tasmota microcontroller and relay board. This system is used to maintain a heating temperature in the home between 70-74°F. Should the solar storage tank drop below 130°F, the heat pumps are enabled in heating mode to bring up the temperature in the home. Alternatively, if the indoor air temperature is above 74°F, the heat pumps will be turned on to cool the space while the radiant heating system is turned off. The Mitsubishi heat pumps are controlled by one DS1 Wi-Fi module each that is directly connected to the control board of each of the interior air handler units. This allows for bidirectional communication with the units that allows the system to send commands, but also to confirm that commands were received and to check on the status of the system. The DS1s are powered directly by the interior air handlers and communicate directly to the automation system. The heat pumps are cycled directly by the conditional logic dictated by the constraints set for indoor air temperature and humidity.

The solar thermal system is actively controlled by the automation system. The first part of doing that involves monitoring water temperatures at various parts of the system as previously discussed. Once the system has that data, it continually ensures heating of the water in the domestic hot water tank by comparing the temperatures of the solar collector and the solar storage tank. If the collector is at a higher temperature, the system cycles the solar pump using an Insteon receptacle to heat the tank. When the tank has a higher temperature than the collector or when the tank temperature reaches 165°F, the pump is cycled off. The domestic hot water recirculation line is monitored to cycle the pump off when the line reaches 110°F. An on-demand hot water heater is used to automatically provide domestic hot water should the temperature of the hot water from the solar storage tank fall below 110°F. The tank temperature, radiant heating, and domestic hot water temperatures are automatically regulated by three thermostatic mixing valves.

The home automation system is used to seamlessly control the home's mechanical systems and are employed toward making the home easier to live in and to make the mechanical systems easy to deal with so that their complexity fades into the background and the inhabitants can focus on rehabilitation. In pursuit of that, but acknowledging that these bounds are not always desired, the systems in the home can also be controlled with an iPad and an Amazon Alexa. The iPad can provide visual feedback on the status of the home and systems within it, but it enables the inhabitants to have control over various parts of the home's comfort systems and lighting. There are smart outlets and smart switches throughout the home that can be turned on or off using the Home Assistant interface on the home's iPad. The smart switches and outlets can also be controlled by voice commands through the Amazon Alexa. All of the outlets and receptacles can be controlled manually using integrated push buttons.

The home automation system will alert the inhabitants to a Demand Response event in their area should it become necessary to modulate their power usage. To reduce the house's energy consumption, the home automation system is equipped to switch into different modes of energy use based on the necessary response. The house is able to run on a “Load Sharing” mode where the heat pumps are used one at a time until the temperatures are satisfied, the ceiling fans can also be cycled with occupancy, and the Tesla battery picks up some of the energy load. If energy consumption is still too high the system will go into “Load Shedding” where both the heat pumps and fans are cycled off, while the clothes washing and drying and electric vehicle charging can be put off until after peak energy usage. The home’s Schneider Electric Wiser Energy monitoring system informs the occupants of the amount of the energy use and shows the energy reductions.

Demand Response

To reduce the peak demand on the batteries, Demand Response schemes such as load shedding and load sharing will be utilized using the home automation system. This can also help reduce the peak loads of the home during normal operation which is an issue in the desert southwest caused by peak summer air conditioning loads. The automation system will use controlled receptacles and control modules to shed or share loads as needed to reduce demand. This capability will be programmed to operate in an automatic mode if needed for utility Demand Response but will also be used to extend battery operation during outages.

The home will have an electric vehicle charging station located on the outside of the mechanical room. This location shortens the electrical run needed for the relatively large energy use. The charger will be able to meet the charging requirement but also can be cycled off if needed for electrical load reduction for Demand Response or load shedding and sharing. A systems integration software is being developed to control vehicle charging and electric clothes dryer during a demand response.

See T-103 Demand Response Scheme for control layout.

Structural Engineering

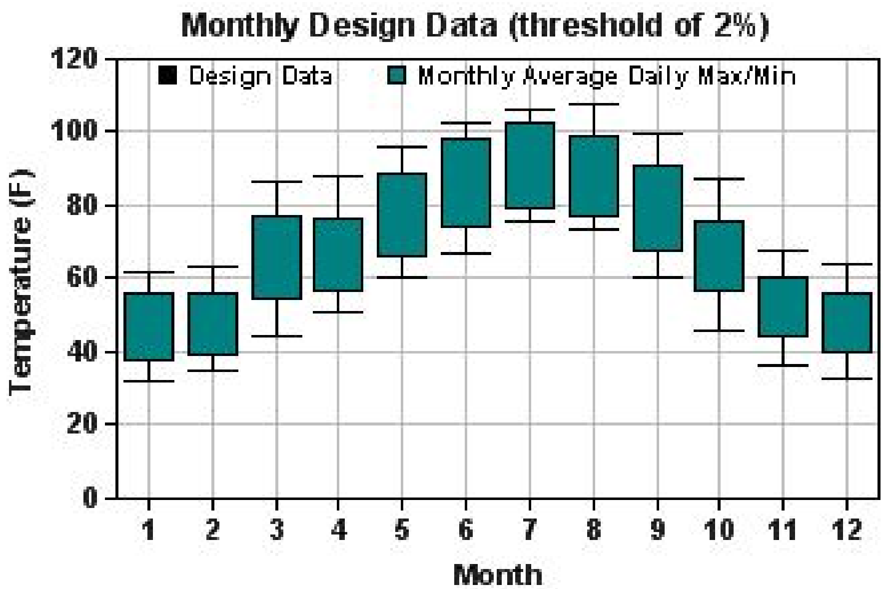
For structural design, the home will be framed with Ahern’s Extreme Cube Space Framing. It offers a solid structural design, and simplifies transportation of the home with forklifting capability. Within the Extreme Cube Spaceframe, there will be well-insulated walls, roof, and floors that utilize advanced framing techniques, as well as energy efficient windows and doors.

Energy Analysis Results and Discussion

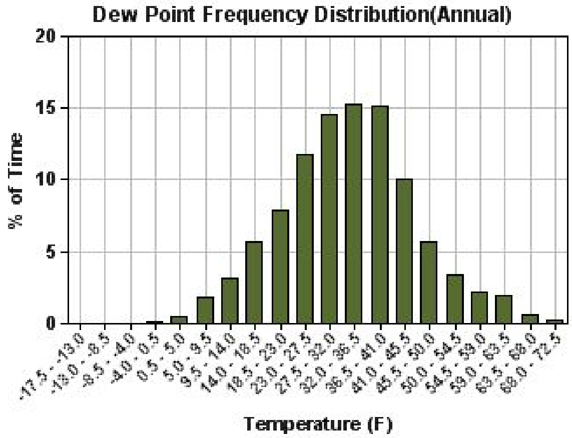
Introduction

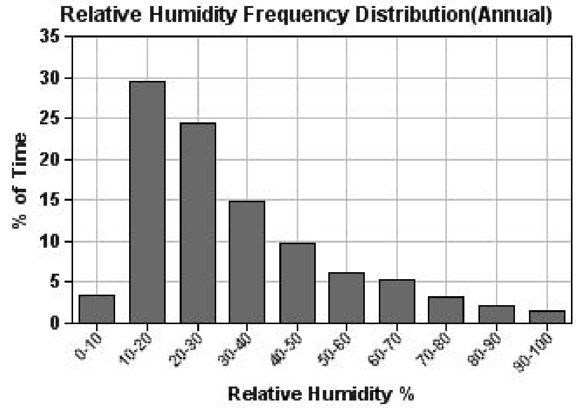
Energy simulations were run to test electricity consumption and the Home Energy Rating (HERS) Index. Various permutations of the design materials under consideration were tested in order to evaluate all possible designs of the house.

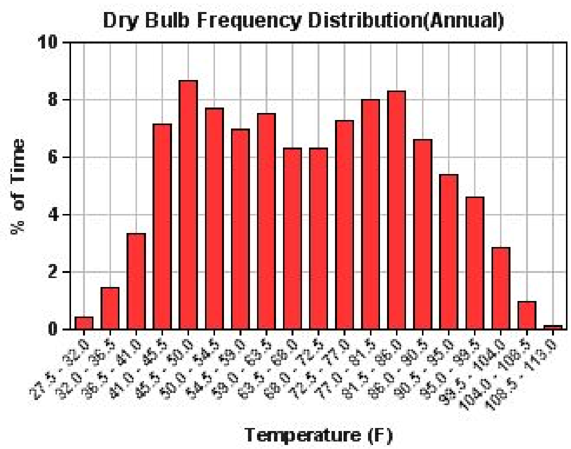
As materials were selected, the simulations allowed us to design other aspects of the house, such as the photovoltaic system, accordingly. Weather and solar data for Las Vegas were used in the evaluation of the performance of the home and systems.

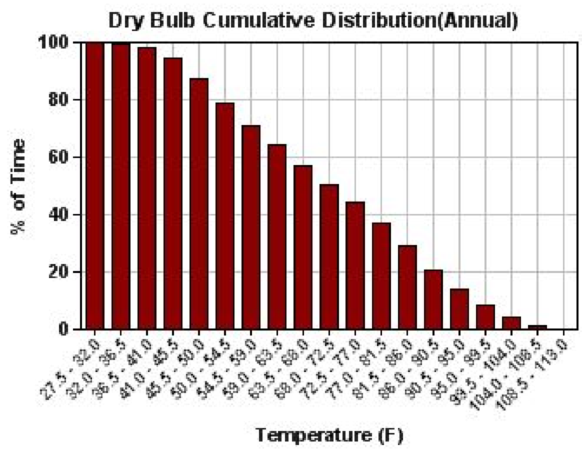


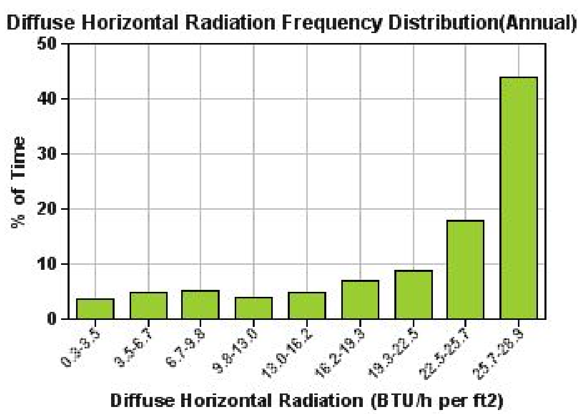
Cooling Degree Day		Heating Degree Day	
Threshold	Value	Threshold	Value
65 °F	3307	65 °F	2180
70 °F	2331	60 °F	1464
75 °F	1522	55 °F	816
80 °F	878	50 °F	346

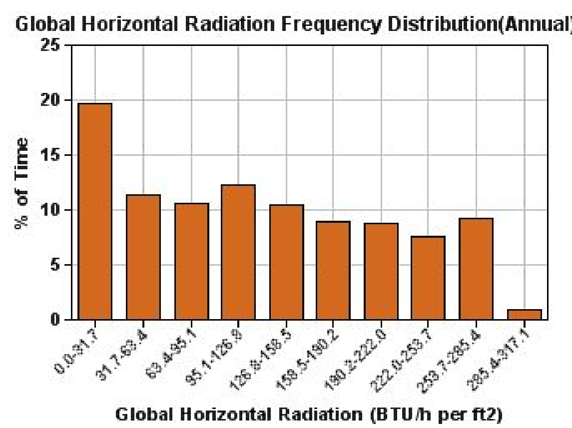

Dew Point Frequency Distribution(Annual)
% of Time
0
5
10
15
20
-17.5 - -13.0
-13.0 - -8.5
-8.5 - -4.0
-4.0 - 0.5
0.5 - 5.0
5.0 - 9.5
9.5 - 14.0
14.0 - 18.5
18.5 - 23.0
23.0 - 27.5
27.5 - 32.0
32.0 - 36.5
36.5 - 41.0
41.0 - 45.5
45.5 - 50.0
50.0 - 54.5
54.5 - 59.0
59.0 - 63.5
63.5 - 68.0
68.0 - 72.5
Temperature (F)

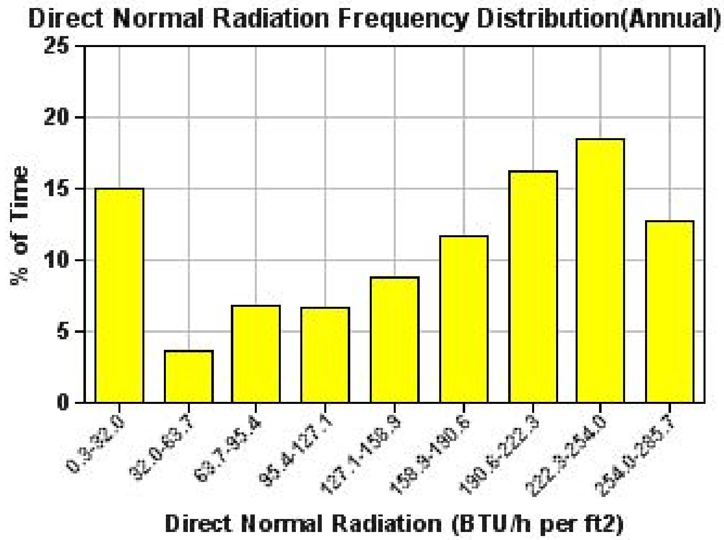

Relative Humidity Frequency Distribution(Annual)
% of Time
0
5
10
15
20
25
30
35
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
Relative Humidity %

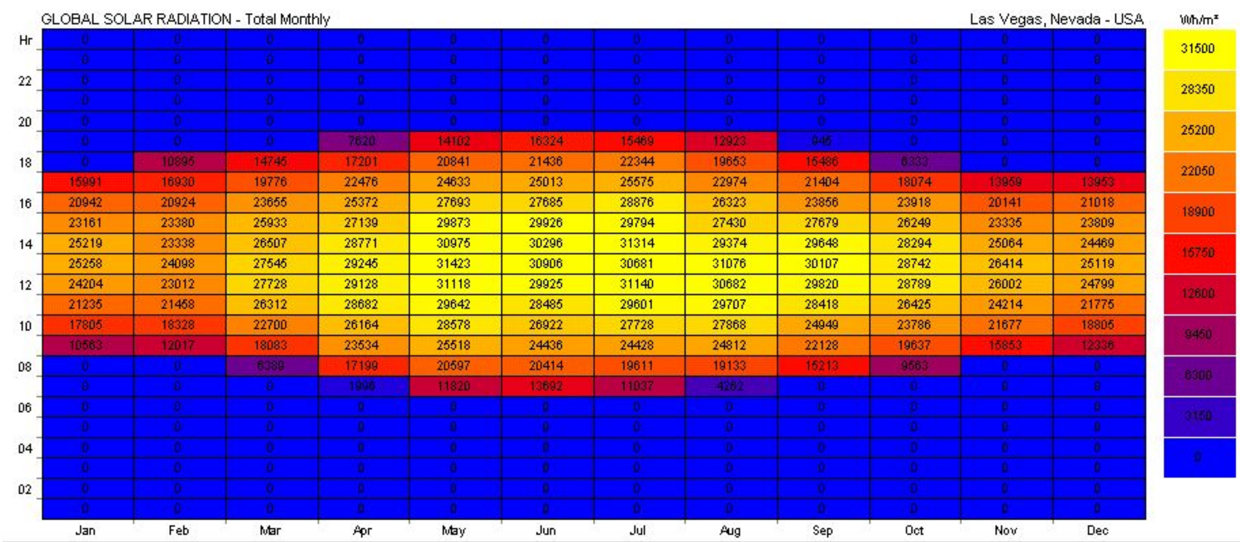

Dry Bulb Frequency Distribution(Annual)
% of Time
0
2
4
6
8
10
27.5 - 32.0
32.0 - 36.5
36.5 - 41.0
41.0 - 45.5
45.5 - 50.0
50.0 - 54.5
54.5 - 59.0
59.0 - 63.5
63.5 - 68.0
68.0 - 72.5
72.5 - 77.0
77.0 - 81.5
81.5 - 86.0
86.0 - 90.5
90.5 - 95.0
95.0 - 99.5
99.5 - 104.0
104.0 - 108.5
108.5 - 113.0
Temperature (F)


Dry Bulb Cumulative Distribution(Annual)
% of Time
0
20
40
60
80
100
27.5 - 32.0
32.0 - 36.5
36.5 - 41.0
41.0 - 45.5
45.5 - 50.0
50.0 - 54.5
54.5 - 59.0
59.0 - 63.5
63.5 - 68.0
68.0 - 72.5
72.5 - 77.0
77.0 - 81.5
81.5 - 86.0
86.0 - 90.5
90.5 - 95.0
95.0 - 99.5
99.5 - 104.0
104.0 - 108.5
108.5 - 113.0
Temperature (F)


Diffuse Horizontal Radiation Frequency Distribution(Annual)
% of Time
0
10
20
30
40
50
0.3-3.5
3.5-6.7
6.7-9.8
9.8-13.0
13.0-16.2
16.2-19.3
19.3-22.5
22.5-25.7
25.7-28.9
Diffuse Horizontal Radiation (BTU/h per ft2)


Global Horizontal Radiation Frequency Distribution(Annual)
% of Time
0
5
10
15
20
25
0.0-31.7
31.7-63.4
63.4-95.1
95.1-126.8
126.8-158.5
158.5-190.2
190.2-222.0
222.0-253.7
253.7-285.4
285.4-317.1
Global Horizontal Radiation (BTU/h per ft2)


Direct Normal Radiation Frequency Distribution(Annual)
% of Time
0
5
10
15
20
25
0.3-32.0
32.0-63.7
63.7-95.4
95.4-127.1
127.1-158.9
158.9-190.6
190.6-222.3
222.3-254.0
254.0-285.7
Direct Normal Radiation (BTU/h per ft2)


GLOBAL SOLAR RADIATION - Total Monthly
Las Vegas, Nevada - USA
Wh/m²
Hr
22
20
18
16
14
12
10
08
06
04
02
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
31500
28350
25200
22050
18900
15750
12600
9450
6300
3150
0

Modeling Software

Rhino 3D
Lumion Pro
PV Watts
System Advisor Model (SAM)
BEopt
REM Rate
Custom Simulation Codes

Rhino was used to ensure coordination between lighting, fire sprinklers, smoke alarms, and ceiling fans, as well as the acoustic absorption system we designed. This system is critical to reducing ambient noise, a known trigger for PTSD. The acoustic panel geometry is driven by balancing the sprinkler spray profile and the need to maximize acoustic absorption; Rhino is an ideal modeling software for an iterative design process that requires complex coordination.

Lumion is a rendering software that works with Rhino to help designers to accurately depict interior materials, daylighting, shade and shadow mapping, and many other attributes essential to evaluating architectural experiences. All computer renderings of the project throughout the design process and all submissions to the competition were created with these two software packages.

BEopt was used to evaluate different building design conditions, framing, insulation materials and thickness, and mechanical systems for performance in the home design. Design elements were evaluated for improving energy performance and for system sizing. Inputs for BEopt can be customized, which allows Team Las Vegas to model the exact R-values for the ceiling, floor, and walls. BEopt outputs various graphs, including the Energy Rating Index. For the HERS score without having the PV modeled, the value is 41.3, and with the PV modeled, a value of -66.4. BEopt found the annual energy consumption to be 4451.72 kWh.

REM Rate was used to compare the home to a code built home and determine the HERs rating for the home, as well as determine the annual loads for the house. Each aspect of the house, such as flooring, walls, windows, doors, and ceiling, was described in detail and given the corresponding R-value as calculated. The heating and cooling systems of the house were also modeled, with some approximations made to model the solar thermal system and how it contributes to the house's heating system. The HERs scores attained in REM Rate are 35 without PV, -67 with PV, and the annual energy consumption is -4,739 kWh.

PV Watts was used to calculate the electricity generation of the photovoltaic system for both Las Vegas and Washington D.C. The Washington D.C. data was evaluated during the competition period. The software was used for the preliminary sizing of the PV system.

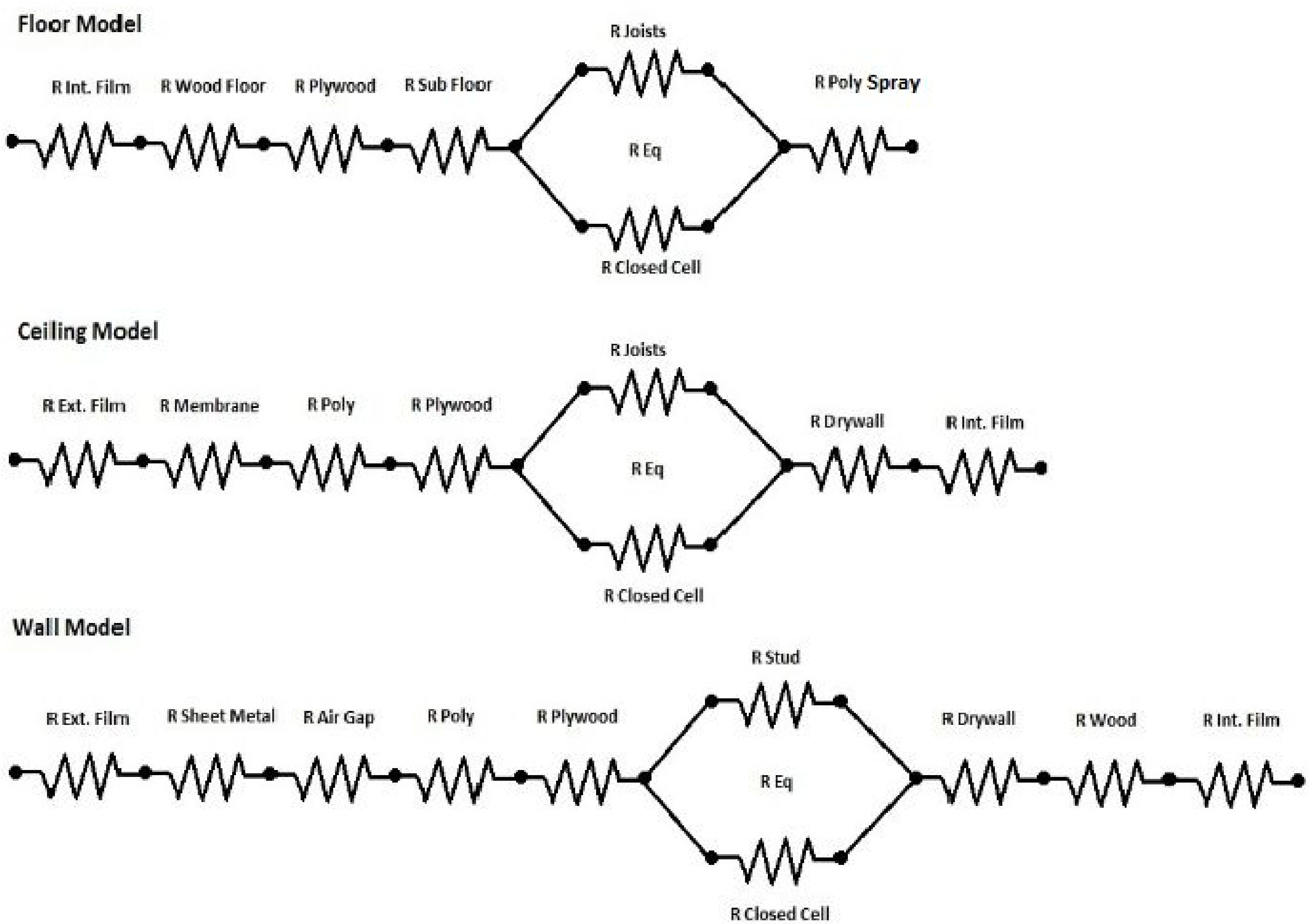
System Advisory Model (SAM) software was used to evaluate the performance and losses of the components of the photovoltaic system. The simulated home energy load from BEopt was evaluated in the code to better size the system and evaluate the performance.

Custom codes and excel sheets were used to examine the optimal angles of solar thermal collectors and the performance at differing installation angles. This is an important evaluation in setting the reconfigurable collector angle.

Calculations of R-values for the major roof, floor, and wall structures were also performed to check building materials, framing spacing, and wall component configurations. The results are shown below.

Results and Discussion

Resistance Analogy



Effective R-Value Analysis

Calculations of the one-dimensional, film-to-film R-values for the roof, wall, and floor structures were used in the building models and to help evaluate design details such as insulation materials and thicknesses, framing techniques and spacing, and building material selection.

Floor Model					
	Thickness or Qty.	Material R value	R value		Total
Interior Film	1	0.25	0.25		0.25
4/4 Wood Floor	1	1	1		1
1/2" Plywood	1	0.63	0.63		0.63
3/4" Plywood	1	0.94	0.94		0.94
Joist Cavity:				R Eq=	43.1
2X10	9.25	1.25	11.563		
Closed Cell Ins.	9.25	6.5	60.125		
Poly Spray	1	0	0		0
				R Total=	**45.92**
Framing Factor	**Thickness**	**FF**	**%**		
Stud	1.5	0.094	9.375		
Insulation	14.5	0.906	90.625		
Parallel Path	**Effective U**	**R Eq**			
	0.023	43.139			
Ceiling Model					
	Thickness or Qty.	**Material R value**	**R value**		**Total**

Exterior Film	1	0.25	0.25		0.25
Roof Membrane	1	0.4	0.4		0.4
2" Cont. Poly. Ins.	2	5	10		10
1/2" Plywood	1	0.63	0.63		0.63
Joist Cavity:				R Eq=	57.9
2X12	11.25	1.25	14.063		
Closed Cell Ins.	11.25	6.5	73.125		
5/8" Drywall	1	0.56	0.56		0.56
Interior Wall Film	1	0.61	0.61		0.61
				R Total=	**70.35**

Framing Factor	**Thickness**	**FF**	**%**
Stud	1.5	0.063	6.25
Insulation	22.5	0.938	93.75

Parallel Path	**Effective U**	**R Eq**
	0.017	57.921

Wall Model

	Thickness or Qty.	**Material R value**	**R value**		**Total**
Exterior Film	1	0.17	0.17		0.17
Sheet Metal Siding	1	0.61	0.61		0.61
7/8" Air Space	1	1	1		1
2" Cont. Poly. Ins.	2	5	10		10
1/2" Plywood	1	0.63	0.63		0.63
Stud Cavity:				R Eq=	27.83
6" Stud	5.5	1.25	6.875		
Closed Cell Ins.	5.5	6.5	35.75		
5/8" Drywall	1	0.56	0.56		0.56
4/4 Ash Hardwood	1	0.71	0.71		0.71
Interior Wall Film	1	0.68	0.68		0.68
				R Total=	**42.19**

Framing Factor	**Thickness**	**FF**	**%**
Stud	1.625	0.068	6.771

Insulation	22.375	0.932	93.229		
Parallel Path	**Effective U**	**R Eq**			
	0.036	27.835			

The high R-values of the ceiling, walls, and floor may have diminishing returns; however, this offsets the amount of glass used around the patio.

Annual Energy Consumption

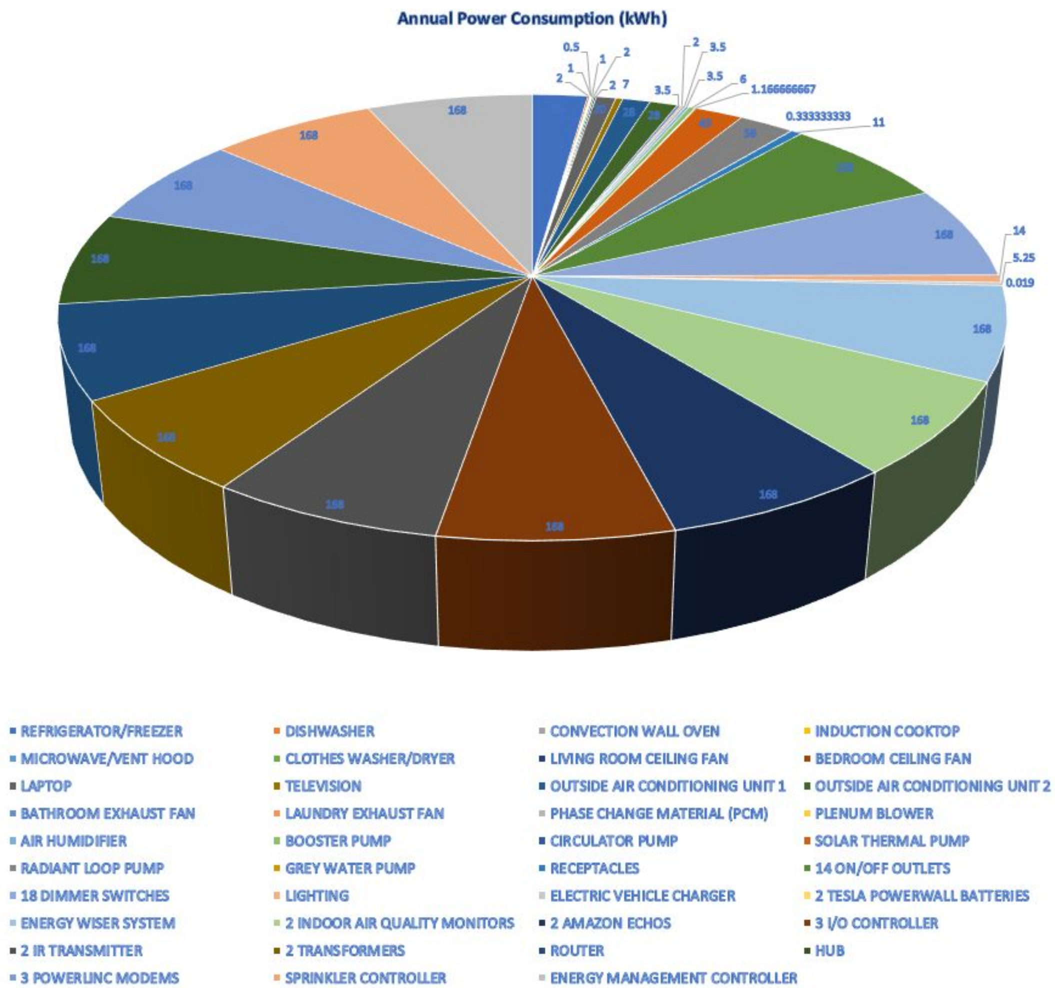
Calculations were made according to available energy guides or rated power consumption and then calculations were made according to predicted usage loads.

Appliance	Usage (Hours/Week)	Rated Power Consumption (Watts)	Annual Electricity Consumption (kWh)	Notes
REFRIGERATOR/FREEZER	56	104	302	lower hours running fridge *changed to 8 hrs a day*
DISHWASHER	2	1080	112.32	Calculated for 1 load per week.
CONVECTION WALL OVEN	1	2850	148.2	Based on typical oven usage.
INDUCTION COOKTOP	0.5	7400	192.4	Based on typical cooktop usage.
MICROWAVE/VENT HOOD	1	636	33.072	Based on typical microwave usage.
CLOTHES WASHER/DRYER	2	1010	105	Calculated for 1 load at 1.5 hours.
LIVING ROOM CEILING FAN	2	20	2.08	Calculated for 2 hours a week during warm months.
BEDROOM CEILING FAN	2	20	2.08	Calculated for 2 hours a week during warm months.
LAPTOP	20	45	46.8	For work/school.
TELEVISION	7	66	0.182	1 hour of watch time each day of the week.
HVAC				
AIR CONDITIONING UNIT 1	56	360	322	8 hours a day during hot months Power consumption Rated (Minimum~Maximum)

AIR CONDITIONING UNIT 2	56	360	322	Cooling W 560 (100 ~ 1,000) Heating W 710 (110 ~ 1,470)
BATHROOM EXHAUST FAN	3.5	36	6.552	Bathroom exhaust fan is on after occupancy.
LAUNDRY EXHAUST FAN	2	36	3.744	Should turn on when the washer and dryer are on and after to vent any remaining sensible and latent heat.
PHASE CHANGE MATERIAL (PCM) PLENUM BLOWER	28	64	93	Runs 4 hrs per day.
AIR HUMIDIFIER	3.5	3	0.168	Run the same time as PCM blower
Solar Thermal				
BOOSTER PUMP	6	5	1.56	Based on typical booster pump usage.
CIRCULATOR PUMP	1.167	59.8	3.628	10 min per day
SOLAR THERMAL PUMP	49	45	114.66	12 hours a day during hot months, 9 hours a day during cold months = 3528 daylight hours
RADIANT LOOP PUMP	56	59.8	66.98	8 hrs per day during heating months
GREY WATER PUMP	0.5	200	5.2	Running 30 min per wk.
WATER HEATER	-	9600	19.2	2 hrs/yr
Electrical				
10 SMART RECEPTACLES	168	0.4	35	Parasitic load.
10 DIMMER SWITCHES	168	0.4	35	Light dimmers are on all the time.
LIGHTING	14	30	21.84	Lights are on during occupancy.
ELECTRIC VEHICLE CHARGER	-	7500	1950	0.3 kwh/mi *25 mi/day * 5 charges/wk
2 TESLA POWERWALL BATTERIES	0.019	2700	2.6676	The batteries will be used only when needed.
ENERGY WISER SYSTEM	168	5	43.68	This monitoring system will be on all the time.
Home Automation				Home automation devices are on 24/7 to continually monitor the house.
1 TRANSFORMER	168	120	524.16	Transformer for radiant manifold

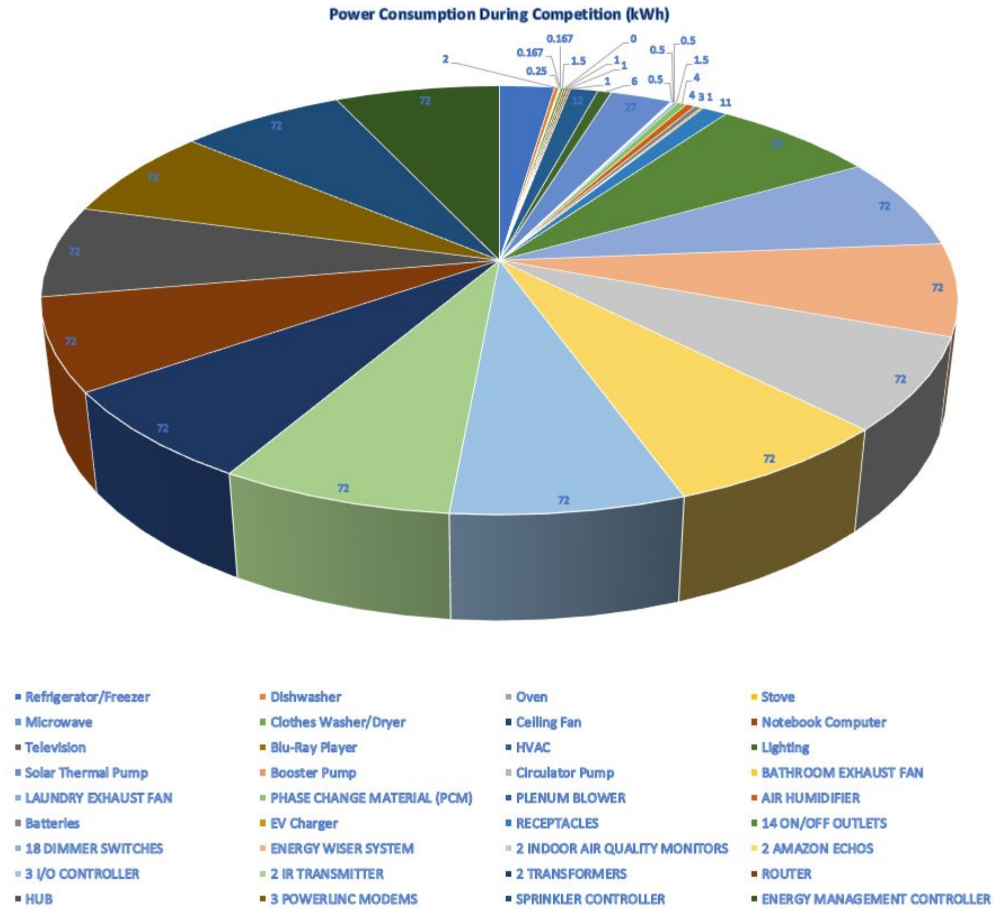
AMAZON ECHO	168	4	17.47	x 2
2 WIFI MODULES	168	0.66	5.77	x 3 controllers
ROUTER	168	0.6	5.24	Router is on all the time.
SPRINKLER CONTROLLER	168	0.6	5.24	Controller is on all the time waiting for its time to be turned on.
RASPBERRY PI	168	2.7	23.59	Raspberry Pi on all the time.
MICRCONTROLLERS	168	0.66	5.77	2 microcontrollers are on all the time.
TOTAL 4123 kWh				

The total value of annual energy consumption calculated is 4123 kWh, and was found to be 4452 kWh in BEopt simulation.



Competition Energy Consumption

Component	Total Time (Hours)	Rated Power Consumption (Watts)	Electricity Consumption in Competition (kWh)
REFRIGERADOR/FREEZER	24	104	2.496
DISHWASHER	2	1080	2.16
OVEN	0.25	2850	0.7125
STOVE	0.167	7300	1.2191
MICROWAVE	0.167	636	0.106212
CLOTHES WASHER/DRYER	1.5	1010	1.515
CEILING FAN	0	66	0
LAPTOP	1	45	0.045
TV	1	66	0.066
HVAC	12	360	4.32
LIGHTING	6	30	0.18
SOLAR THERMAL PUMP	27	54	1.458
BOOSTER PUMP	0.5	5	0.0025
CIRCULATOR PUMP	0.5	59.8	0.0299
BATHROOM EXHAUST FAN	0.5	36	0.018
LAUNDRY EXHAUST FAN	1.5	36	0.054
PHASE CHANGE MATERIAL (PCM) PLENUM BLOWER	4	106	0.424
AIR HUMIDIFIER	4	3	0.012
BATTERIES	3	2700	8.1
ELEC VEHICLE CHARGER	1	7.5	7.5
10 SMART RECEPTACLES	72	4	0.288
10 DIMMER SWITCHES	72	4	0.288
ENERGY WISER SYSTEM	72	5	0.36
1 INDOOR AIR QUALITY MONITOR	72	4	0.288
AMAZON ECHO	72	4	0.288
TOTAL 25 kWh			


Power Consumption During Competition (kWh)
Refrigerator/Freezer
Dishwasher
Oven
Stove
Microwave
Clothes Washer/Dryer
Ceiling Fan
Notebook Computer
Television
Blu-Ray Player
HVAC
Lighting
Solar Thermal Pump
Booster Pump
Circulator Pump
BATHROOM EXHAUST FAN
LAUNDRY EXHAUST FAN
PHASE CHANGE MATERIAL (PCM)
PLENUM BLOWER
AIR HUMIDIFIER
Batteries
EV Charger
RECEPTACLES
14 ON/OFF OUTLETS
18 DIMMER SWITCHES
ENERGY WISER SYSTEM
2 INDOOR AIR QUALITY MONITORS
2 AMAZON ECHOS
3 I/O CONTROLLER
2 IR TRANSMITTER
2 TRANSFORMERS
ROUTER
HUB
3 POWERLINC MODEMS
SPRINKLER CONTROLLER
ENERGY MANAGEMENT CONTROLLER

Thermal Load

Project Summary

Location and Weather	
Project	UNLV Solar Decathlon
Address	4505 S. Maryland Pkwy, Las Vegas, NV
Latitude	36.26°
Longitude	-115.24°
Summer Dry Bulb	109 °F
Summer Wet Bulb	73 °F
Winter Dry Bulb	28 °F
Mean Daily Range	25 °F

FORM J1AE • ABRIDGED VERSION of MANUAL J, 8TH EDITION

Project	Mojave Bloom	Design State & City	Nevada	Las Vegas AP	
Indoor Design Heating db	70	@ Outdoor (Winter) 99% db	30	HTD	40
Indoor Design Cooling db	75	@ Outdoor (Summer) 1% db	106	CTD	31
Indoor Design Cooling RH	50%	Grains Difference	-32	Daily Range	High
Latitude	36	Elevation	2162	ACF	0.930

	Glass Direction	Construction Detail	Heating HTM	Cooling HTM	Net Area	Block Load Heating BTUH	Block Load Cooling BTUH	Room--> Net Area	Hallway BTUH Heating	Hallway BTUH Cooling	Room--> Net Area	Bathroom/Bedroom BTUH Heating	Bathroom/Bedroom BTUH Cooling	Room--> Net Area	Living Room BTUH Heating	Living Room BTUH Cooling	Room--> Net Area
Partition Ceilings	d																
	e																
11 Passive Floors	a																
	b																
Exposed Floors	c	Floor, R40	1.00	0.78	512	512	397	60	60	47	240	240	186	212	212	164	
Slab (Perimeter Ft.)	d																
Basement Floor	e																
Partition Floors	f																
	g																
12 Infiltration	Envelope Leakage: Tight; No. of Fireplaces	Heated & Cooled Floor Area = Sq. Ft.: 512	Above Grade = Cu. Ft.					VAR 0.20			VAR 0.30			VAR 0.50			VAR
13 Internal Gains		Number of Bedrooms: 3; Appliance - 0 BTUH	Occupants	4			#VALUE!										
14 Sub Totals						4467	#VALUE!		711	1332		1296	1901		2460	4407	
15 Duct Loss & Gain		TF-Ducts in Conditioned Space; R-Value = 8; Leakage Class .06/.06; Installed Square Feet of Surface or Default = 1; Supply	1 ☑	Return ☑	1		#VALUE!										
16 Ventilation	Combustion Air From Conditioned Space	☐ Furnace ☐ Water Heater	None														
19 Blower Heat Gain		Manufacturer's performance data has no blower heat discount					1707										
20 Total Sensible Loss or Gain						4467	#VALUE!		711	1332		1296	1901		2460	4407	

Team Las Vegas 4505 South Maryland Parkway Las Vegas, Nevada, 89154	21	Latent Infiltration load for cooling				
		Latent load for occupants				800
		Latent load for plants	Small	Medium: 100	Large	2000
		Latent load for duct in unconditioned space				
		Latent ventilation load for cooling				
		Total Latent Gain				2800

Home | Read Me | J1 Form | Summary | Glass Sched | Doors | Glass | Walls | Ceilings | Floors | Help | What to do next | Notes

Solar Thermal Simulation

Team Las Vegas used a model developed from a former UNLV master's thesis checking performance of various evacuated tube collectors mounted at different angles. Using values from that model, Team Las Vegas found that south-facing 51 deg was optimal for a collector in Las Vegas. The unique part of Team Las Vegas' design is that the angle of the collector is easily adjustable. Therefore, the angle can be changed to optimize performance seasonally or locally. This also allows the collector to be recessed into the wall for transportation. Team Las Vegas' collector is mounted on the south wall-not on the roof; therefore, wind load and uplift calcs were considered but not significant. Since prevailing wind in Las Vegas is from the south to southwest, and the home's facing the south, the wind will be distributed not only on the collector but the south facing exterior wall of the home. Wind coming from the north will not hit the collector, since the north facing exterior wall of the home blocks it. East and west winds will have minimal wind load on the collector, because they will be going over the sides of the collector. There's not enough surface on the side of the evacuated tubes to have an effect. Therefore, wind load and uplift are minimal on the home's collector.

Hydronic Radiant Floor Simulation

Team Las Vegas worked with Uponor technicians to design the radiant flooring system. The resulting total project heat loss can be considered the rate of heat that the system is designed to provide. The heating of the house is thus primarily met by hydronic radiant, which is driven by solar thermal energy input. Using their software, Advanced Design Suite, Uponor calculated and found the following information:

Project Summary

Project #:	32646H
Project Name:	UNLV Solar Decathlon
Design Data Location:	Las Vegas, Nevada
Outdoor Temperature:	30 °F
Wind Speed:	19 mph
Total Area:	439 ft²
Heated Area:	439 ft²
Construction Quality:	Best
RFH Glycol Level:	100% Water
Design Temp. Drop:	20 °F (20 °F for all QuikTrak)
Radiant Tubing Volume:	2.6 gallons(US)
Volume Water:	2.6 gallons(US)
Volume Glycol:	0 gallons(US)
Total Flowrate:	0.7 USGPM
Maximum Head Loss:	6.1 ft(H2O)
Total Loops:	4
Total Manifolds:	1
Total Zones:	3
Min. Tubing Required:	745 ft
Total Load:	12,282 Btu/hr
Total Radiant Load:	6,550 Btu/hr
Total Supplemental Load:	5,239 Btu/hr

Radiant Design Data

Manifold 1

Water Temperature:	109.5 °F
Zone Control:	Actuators
Control Method:	None/Other
Total Loops:	4
Flow Rate:	0.7 USGPM
Head Loss:	6.1 ft(H2O)
Head Loss S/R:	0 ft(H2O)
S/R Tube Length (One way):	0 ft
S/R Tube Type:	hePEX 3/4"

Room	Zone #	Attach Method	Tube Type	Loop #	Area	Unit Heat	Tube Spacing	Leader Length	Loop Length	Flow Rate	Head Loss	Valve Turns	Cover Rv	Surface Temp.	Req. Water Temp.	Design Temp. Drop
Bedroom / Bathroom Hall - Floor	2	Quik Trak	hePEX 5/16"	1	70	20.0	7	10	145	0.2	2.2	.4	0.7	80	109.4	20
Kitchen / Living Room / Main Hall - Floor	3	Quik Trak	hePEX 5/16"	1	94.5	20.1	7	10	215	0.2	5.4	.7	0.7	80	109.5	20
Bedroom / Bathroom Hall - Floor	2	Quik Trak	hePEX 5/16"	2	70	20.0	7	10	140	0.2	2.1	.4	0.7	80	109.4	20
Kitchen / Living Room / Main Hall - Floor	3	Quik Trak	hePEX 5/16"	2	94.5	20.1	7	10	245	0.2	6.1	4.2	0.7	80	109.5	20

Photovoltaic Simulation

I. Choice of panels

The panels selected are SunPreme HXB-400 Bifacial Panels which are rated to provide 400W and 480W with the bifacial boost. The design consists of 16 panels that are placed on the roof in two parallel strings of 8 panels. Each panel is connected to DC optimizers which are fed into the SolarEdge Technologies 7600H inverter/EV charger.

The panels will be positioned at a 10 degree angle for the competition height. For transportation, the panels will be at a horizontal position, however, during the competition period they can be deployed to the 10 degree angle. Furthermore, at the house's final location that angle can be adjusted to a more optimal angle for energy generation.

II. Energy Production

With 16 panels, the total annual energy production is projected to be 12,071 kWh. For the month of May, the energy production in Las Vegas, NV is projected to be 1,310 kWh. The electrical load for that month was projected to be 337.9 kWh. The difference in energy production and energy load may seem large at first, but this is because the home needs to be able to produce enough energy off grid to power the home, charge the batteries, and charge an electric vehicle (EV). The home loads were calculated using REM/RATE, BeOPT, and energy consumption tables found in the Energy Analysis section. These values were modeled in the System Advisory Model(SAM) to evaluate the size and the performance of the photovoltaic array (PV). The graphs and data points shown are derived from the SAM program.

III. DC/AC Ratio and Inverter

The DC/AC ratio is a measurement of the DC energy produced divided by the AC energy output rating of the inverter. For this system, the DC power produced is 6.4 kW and the inverter rating is 7.6 kW giving the system a DC/AC ratio of 0.84 which means that there will be minimal clipping and power loss due to the inverter operating at maximum power. A DC/AC ratio that is above 1 will produce clipping which leads to power loss and inefficiency. In the desert southwest, a rating above 1.0 can damage the system while operating in higher temperatures.

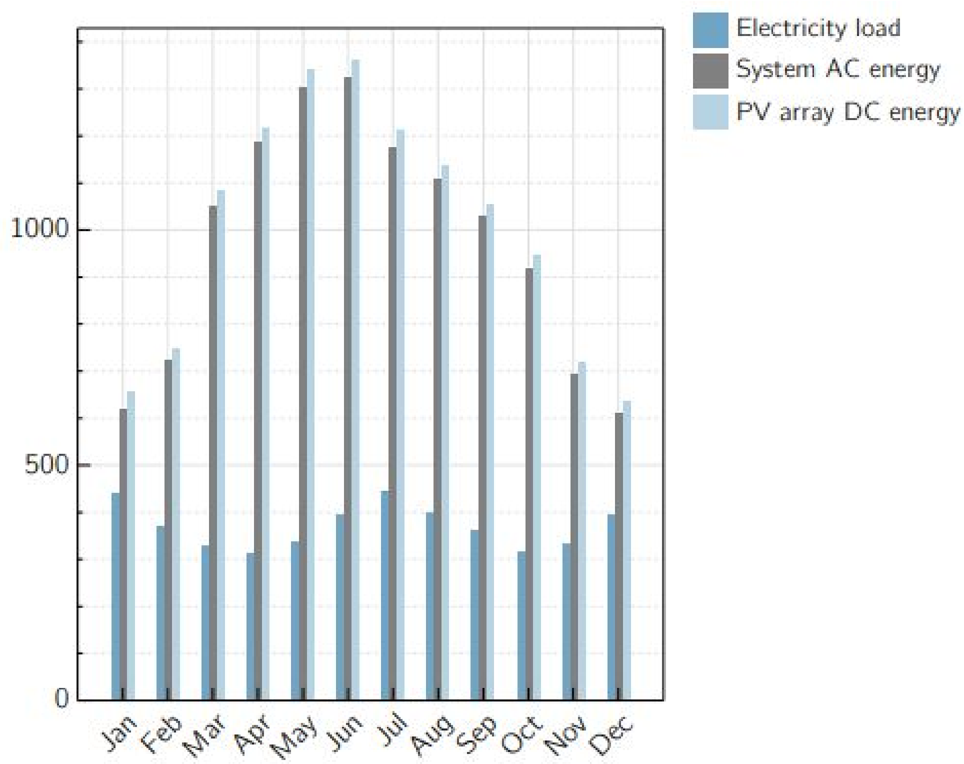
IV. DC Optimizers

Model P505 DC optimizers are being used to improve the performance of the system. These are needed for the bifacial panels because of the differential backlighting of the panels. DC optimizers are recommended to mitigate all types of module mismatch-loss from manufacturing tolerance to partial shading.

Electricity Load from BEopt

Time Stamp	Electricity Load (kWh/mo)
Jan	443.201
Feb	369.79
Mar	330.566
Apr	311.227
May	337.882
Jun	395.575
Jul	447.134
Aug	398.605
Sep	364.104
Oct	315.689
Nov	334.23
Dec	397.171

Photovoltaic System Energy Data from SAM



System Advisory Model (SAM) Annual Calculated Values

Metric	Value
Annual energy (year 1)	11,740 kWh
Capacity factor (year 1)	20.9%
Energy yield (year 1)	1,832 kWh/kW
Performance ratio (year 1)	0.83
Battery efficiency (incl. converter + ancillary)	90.71%
Levelized COE (nominal)	11.66 ¢/kWh
Levelized COE (real)	9.31 ¢/kWh
Electricity bill without system (year 1)	$833
Electricity bill with system (year 1)	$164
Net savings with system (year 1)	$669
Net present value	$-4,863
Simple payback period	Inf
Discounted payback period	Inf
Net capital cost	$29,145
Equity	$0
Debt	$29,145

Projected Monthly Electricity Bill from SAM

	Electricity load (kWh/mo)	Electricity bill with system ($/mo)	Electricity bill without system ($/mo)
Jan	443.201	20.9813	76.933
Feb	369.79	13	65.7609
Mar	330.566	13	60.5337
Apr	311.227	13	58.8178
May	337.882	13	68.4319
Jun	395.575	13	76.3159
Jul	447.134	13	83.2126
Aug	398.605	13	76.7308
Sep	364.104	13	70.6073
Oct	315.689	13	64.5723
Nov	334.23	13	61.5197
Dec	397.171	13	70.0414

Photovoltaic DC-AC System Energy from SAM

Time Stamp	PV Array DC Energy (kWh/mo)	System AC Energy (kWh/mo)	Electricity Load (kWh/mo)
Jan	664.482	625.95	443.201
Feb	743.095	717.35	369.79
Mar	1089.51	1054.02	330.566
Apr	1211.6	1178.91	311.227
May	1310.81	1275.19	337.882
Jun	1356.05	1318.73	395.575
Jul	1220.48	1184.69	447.134
Aug	1173.04	1140.08	398.605
Sep	1077.97	1049.6	364.104
Oct	943.412	915.109	315.689
Nov	730.026	703.451	334.23
Dec	604.123	577.268	397.171

Irradiance from SAM

Time Stamp	POA Rear-Side Irradiance Total (kWh/mo)	POA Irradiance Total After Shading & Soiling (kWh/mo)	POA Front-Side Irradiance Total (kWh/mo)	POA Front-Side Irradiance Beam After Shading & Soiling (kWh/mo)
Jan	172.987	3547.42	3374.44	2656.22
Feb	176.162	4079.79	3903.63	3012.5
Mar	226.893	5960.74	5733.84	4449.33
Apr	251.4	6779.03	6527.63	4959.51
May	297.838	7757.22	7459.38	5785.65
Jun	318.771	7976.84	7658.07	6413.19
Jul	288.764	7276.32	6987.55	5357.05
Aug	260.25	7003.99	6743.73	5512.65
Sep	232.997	6379.95	6146.96	5064.27
Oct	214.637	5234.52	5019.88	4093.29
Nov	185.513	3954.05	3768.54	3138.01
Dec	164.669	3207.29	3042.62	2406.42

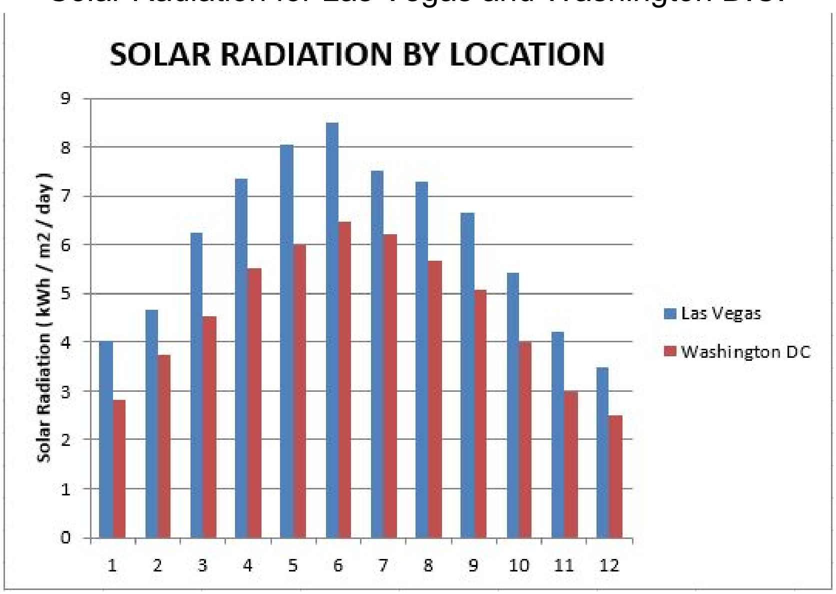
Las Vegas, Nevada

Output of the photovoltaic system was evaluated for the energy production for Las Vegas and for Washington D.C. A PV generation analysis was also performed using PV Watts.

Evaluation of a 6.4 kW PV system for Las Vegas

Las Vegas		Lat, Lon: 36.09, -115.14	
Month	**Solar Radiation (kWh / m2 / day)**	**AC Energy (kWh)**	**Value ($)**
January	4.03	640	78
February	4.65	659	80
March	6.25	961	117
April	7.36	1,075	131
May	8.06	1,172	142
June	8.49	1,188	144
July	7.5	1,069	130
August	7.28	1,048	127
September	6.67	942	114
October	5.41	823	100
November	4.22	637	77
December	3.5	559	68
Annual	6.12	10,773	$1,308

Solar Radiation for Las Vegas and Washington D.C.

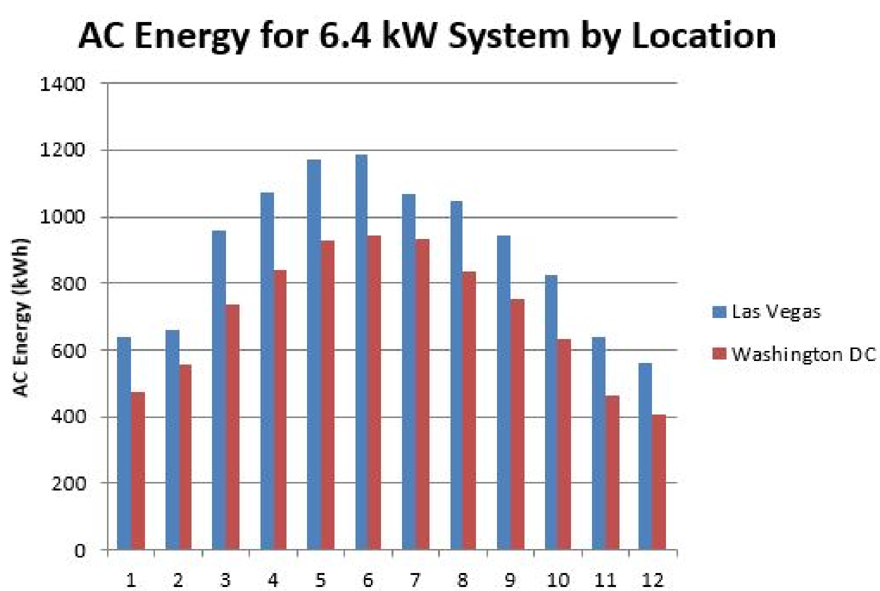


Output of the photovoltaic system was evaluated for the energy production for Washington, D.C. The PV generation analysis was also performed using PV Watts.

Simulation of the 6.4 kW system performance in Washington D.C.

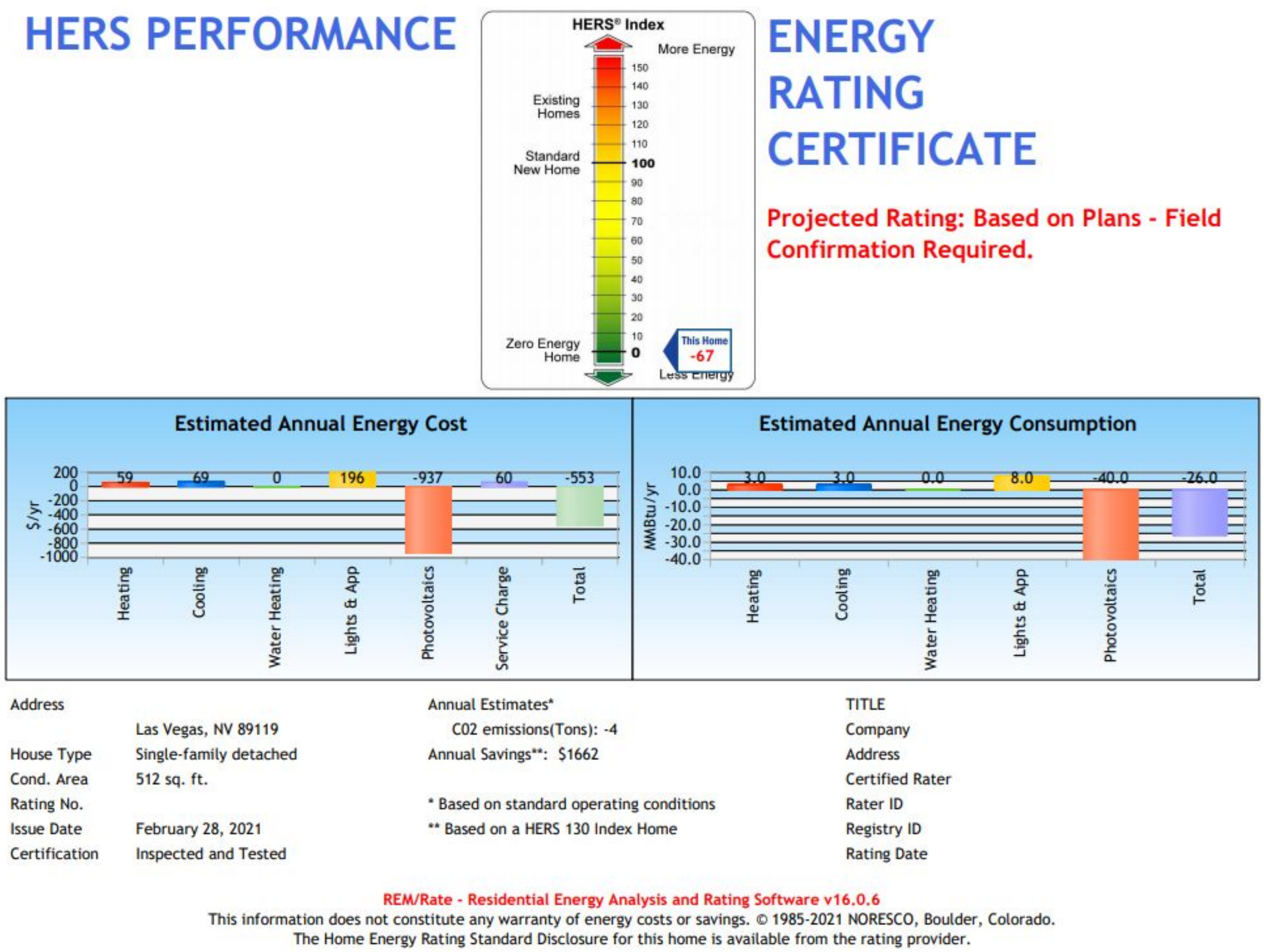
Washington, D.C.	Lat, Lon: 38.89, -77.02		
Month	**Solar Radiation (kWh / m2 / day)**	**AC Energy (kWh)**	**Value ($)**
January	2.83	472	57
February	3.75	555	67
March	4.53	738	89
April	5.51	841	101
May	5.98	928	111
June	6.46	942	113
July	6.23	935	112
August	5.67	837	100
September	5.08	753	90
October	4	631	76
November	2.99	461	55
December	2.5	407	49
Annual	4.63	8,500	$1,020

A comparison of the system performance between Las Vegas and Washington D.C.



Whole Building Energy Modeling

REM/Rate™ was used to evaluate the home's energy efficiency and determine the Home Energy Rating System Index which rates the home's performance. The current design scored a HERS rating of 35 without the PV system. With the addition of PV to the home the HERS score dropped below zero to a value of -67 and the PV system needed to charge the batteries during the day while operating in an off-grid mode.



Effective Overall U-Value

2018 IECC Building UA Compliance

Property
Las Vegas, NV 89119

Weather:Las Vegas, NV
Desert Bloom
Final Case With PV - Copy.blg

Organization
Team Las Vegas

Builder

HERS
Projected Rating
Rater ID:

Elements	**Insulation Levels** 2018 IECC	As Designed
Shell UA Check		
Ceilings:	15.8	7.1
Skylights:	2.4	1.9
Above-Grade Walls:	106.4	71.3
Windows and Doors:	77.5	67.9
Floors Over Ambient:	24.1	13.5
Overall UA (Design must be equal or lower):	226.2	161.6

Mandatory Requirements

The following Mandatory Requirements Fail:

The Tested home infiltration level is above the 3.0 ACH50 limit set by IECC 2018 and as a result fails the UA Compliance Path.

Compliant mechanical ventilation is required in the home. This home has insufficient mechanical ventilation specified.

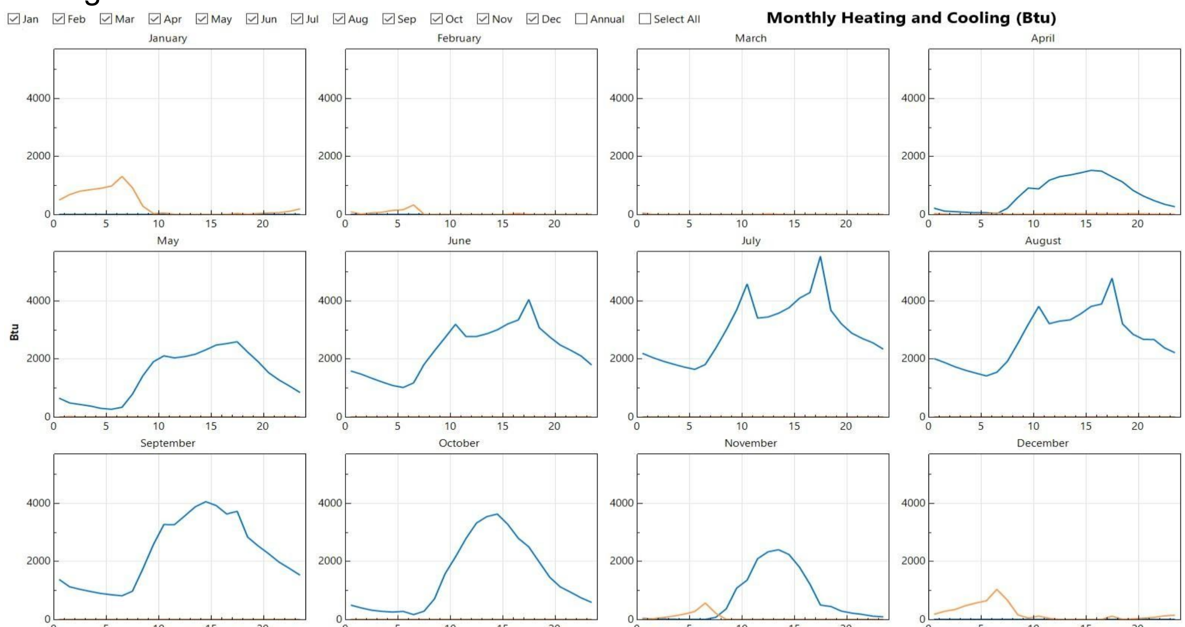
Mandatory Requirements Check Box (IECC_18)

This home DOES NOT MEET the overall thermal performance requirements and verifications of the International Energy Conservation Code based on a climate zone of 3B. (Section 402, International Energy Conservation Code, 2018 edition.)

Name		Signature	
Organization	Team Las Vegas	Date	28 February 2021

REM/Rate - Residential Energy Analysis and Rating Software v16.0.6
This information does not constitute any warranty of energy costs or savings.

BEopt™ was also used to model the performance of the home and helped make design decisions on construction techniques, materials, insulation materials and thicknesses, mechanical systems, and energy systems used in the home design. The major components of the home were modeled then changes to individual systems were evaluated to better select an efficient and affordable design.



The overshoot in heating seen in March and April is due to the low solar angle through the south-facing windows. This overheating can be absorbed by the phase change material (PCM) in the fresh air plenum and used for heating during the late evening hours.